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ABSTRACT

This course in energy audits is one of 16 courses in the Energy Technology Series developed for an Energy Conservation-and-Use Technology curriculum. Intended for use in two-year postsecondary technical institutions to prepare technicians for employment, the courses are also useful in industry for updating employees in company-sponsored training programs. Comprised of 11 modules, the course overviews the purpose, objectives, and mechanics of the energy audit process. Full background and procedural instructions precede case studies and laboratory practice in auditing. In the final module the students undertake audit analyses and recommend remedial actions based on analyses of their practice audits. Written by a technical expert and approved by industry representatives, each module contains the following elements: introduction, prerequisites, objectives, subject matter, exercises, laboratory materials, laboratory procedures (experiment section for hands-on portion), data tables (included in most basic courses to help students learn to collect or organize data), references, and glossary. Module titles are Total Energy Management, Elements of an Energy Audit, Energy Audit Procedures and Analyses, Building Systems, Lighting Systems, Auditing HVAC Systems--Parts I and II, Auxiliary Equipment Systems, Process Energy Systems, Applications of Solar Energy, and Energy Audit Workbook. (YLB)

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ENERGY AUDITS

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
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PREFACE

ABOUT ENERGY TECHNOLOGY MODULES

The modules were developed by CORD for use in two-year postsecondary technical institutions to prepare technicians for employment and are useful in industry for updating employees in company-sponsored training programs. The principles, techniques, and skills taught in the modules, based on tasks that energy technicians perform, were obtained from a nationwide advisory committee of employers of energy technicians. Each module was written by a technician expert and approved by representatives from industry.

A module contains the following elements:

Introduction, which identifies the topic and often includes a rationale for studying the material.

Prerequisites, which identify the material a student should be familiar with before studying the module.

Objectives, which clearly identify what the student is expected to know for satisfactory module completion. The objectives, stated in terms of action-oriented behaviors, include such action words as operate, measure, calculate, identify, and define, rather than words with many interpretations such as know, understand, learn, and appreciate.

Subject Matter, which presents the background theory and techniques supportive to the objectives of the module. Subject matter is written with the technical student in mind.

Exercises, which provide practical problems to which the student can apply this new knowledge.

Laboratory Materials, which identify the equipment required to complete the laboratory procedure.

Laboratory Procedures, which is the experiment section, or "hands-on" portion, of the module (including step-by-step instruction) designed to reinforce student learning.

Data Tables, which are included in most modules for the first year (or basic) courses to help the student learn how to collect and organize data.

References, which are included as suggestions for supplementary reading/viewing for the student.

Test, which measures the student's achievement of prestated objectives.

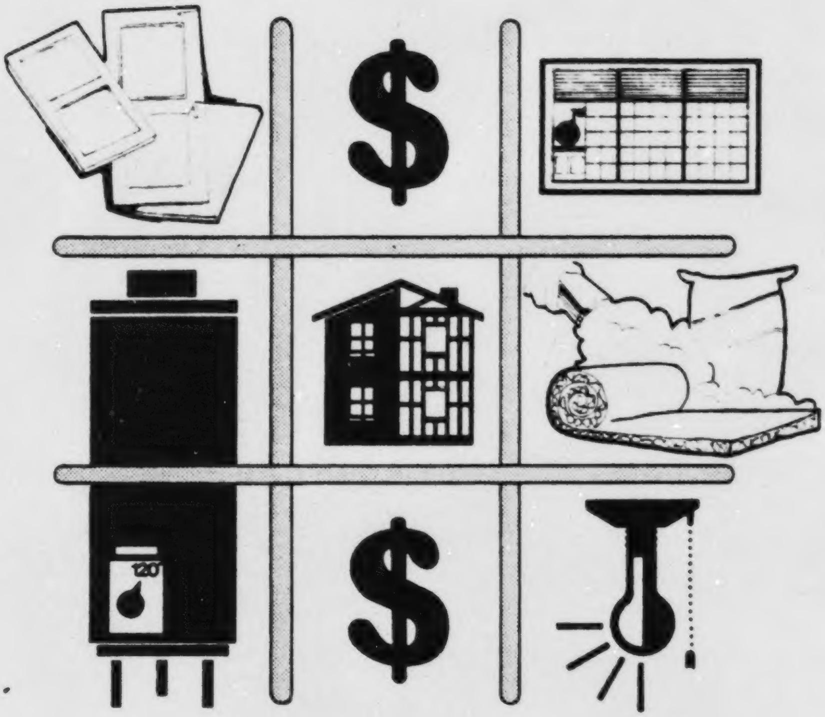
CONTENTS

Preface
Table of Contents
MODULE EA-01 Total Energy Management
MODULE EA-02 Elements of an Energy Audit
MODULE EA-03 Energy Audit Procedures and Analyses
MODULE EA-04 Building Systems
MODULE EA-05 Lighting Systems
MODULE EA-06 Auditing HVAC Systems — Part I
MODULE EA-07 Auditing HVAC Systems — Part II
MODULE EA-08 Auxiliary Equipment Systems
MODULE EA-09 Process Energy Systems
MODULE EA-10 Applications of Solar Energy

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY AUDITS



MODULE EA-01

TOTAL ENERGY MANAGEMENT

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

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CORD

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INTRODUCTION

This module introduces the energy audit within the context of total energy management. "Total Energy Management" begins with an overview of fundamental energy use systems, the basics of heat loss and gain, major energy use systems, and the energy use characteristics of specific building types. There is also a discussion of utility company billing procedures and of the components of the utility energy bill.

PREREQUISITES

The student should be familiar with energy conservation principles.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Describe the interrelationships between the fundamental building systems — energized, non-energized, and human.
2. Define and describe a building's major energy use system.
3. Explain utility company energy bills and billing procedures.
4. Convert raw energy consumption data into an Energy Utilization Index.

TOTAL ENERGY MANAGEMENT AND THE ENERGY AUDIT

Energy auditing has much in common with other types of auditing. The auditor is a specialist who understands all parts of a particular system: corporate finances, automobile drive trains, microcomputer assembly lines, and so forth. The auditor also understands how the parts work together and how they affect each other. For example, an accountant, through analysis of the complicated records of a company's revenue, expenses, and other financial matters, can assemble a clear picture of the company's fiscal situation. On the basis of this information, the financial auditor can recommend ways for the company to operate more profitably – more efficiently.

In the same way, the energy auditor is a specialist in energy use and conservation who analyzes the complicated ways in which a building uses energy. Based on this analysis, the auditor can recommend changes for use of the building and its equipment that will increase energy efficiency. These recommendations, compiled in a total energy management plan, can get the same amount of work done with less energy and lower energy cost.

THE ENERGY AUDIT

Energy audits have been performed since humans began using external energy sources. The survival of prehistoric cave dwellers must often have depended on getting the maximum amount of warmth and light from a scanty supply of firewood.

When modern city dwellers see the pile of wood for fireplaces shrinking, they face the same problem. Although most of today's energy consumers are not concerned with survival, effective energy management usually means more comfort and enjoyment.

However, the urgent need for trained energy auditors — especially qualified energy use and conservation technicians — stems from a single, critical fact: inexpensive energy is a thing of the past. Each reduction in energy supply and each increase in energy cost makes energy conservation a more crucial concern for everyone.

To conserve energy is to reduce the amount of fuel and electricity required for a system (such as a building) to serve its intended purpose. Reductions in energy consumption save money. As the price of energy continues to rise, improvements made now in energy efficiency (that is, the amount of work performed per unit of energy) will produce increasing savings. The energy audit is the first step toward managing energy with maximum efficiency.

The energy audit assumes many forms. Some are simple; some are complicated. The energy audit's main features, however, are always the same: it is an evaluation of how a particular system (such as building), including all of the energy-using systems it contains, uses and/or wastes energy. The qualified energy auditor should be thoroughly familiar with: (1) energy use and conservation technology; (2) auditing procedures and processes; (3) the economics of investing in energy conservation; and (4) ways to explain this technical information to building owners, managers, and operators in a way that encourages them to take action.

With this information and skill, the energy auditor can recommend a total energy management plan for any particular application. When put into action, this plan saves the building owner/operator's money, and helps the nation by conserving natural resources and reducing dependence on imported energy supplies.

TYPES OF AUDITS

Typical energy audits may be classified in one of three categories: walk-through audits, mini-audits, and maxi-audits.

Walk-Through Audits

The walk-through audit is the quickest and least expensive to perform of all audits. By means of a visual inspection, the auditor performing a walk-through audit can identify preliminary energy-saving potential, determine maintenance and operational energy-saving opportunities, and collect the information necessary to determine if there is a need for a more extensive audit.

Mini-Audits

A mini-audit involves tests and measurements that detail energy use and energy waste. In addition, the mini-audit includes calculations of the economics of making recommended energy-efficiency improvements.

Maxi-Audits

To the walk-through and mini-audits, the maxi-audit adds an analysis of the energy use characteristics and energy consumption of each of the building's major energy use systems, such as HVAC, lighting, and industrial processes. It is based upon analysis of a model of the building – often a computer simulation or detailed architectural drawings. The maxi-audit analyzes annual energy use, and takes into account climatological data.

OTHER BENEFITS OF ENERGY CONSERVATION

In addition to reducing energy consumption and expense, there are many other benefits that come from effective energy auditing, conservation, and management. Additional benefits are the following:

- Extension of the useful life of existing equipment and prevention of unnecessarily early replacement of equipment.
- Increase of the reserve capacity of existing central electricity generating plants and the ability to meet future demands without having to install more generating capacity.
- Reduced likelihood of shutdowns or curtailment of operations due to fuel or power shortages.
- Reduction in pollution, which results from the combustion of fossil fuels, and a consequent reduction in the cost of pollution control equipment.

- Reduction of fuel waste without a reduction of health and comfort standards or a reduction of a building's serviceability.
- Reduction in peak electric loads and electric power demand charges and a reduction of the load on power generating and distribution systems.

BASIC CONCEPTS OF TOTAL ENERGY MANAGEMENT

FUNDAMENTAL BUILDING SYSTEMS

Buildings have three fundamental systems that affect energy use: energized systems, non-energized systems, and human systems.

Energized Systems

Energized systems are those systems that consume energy directly. Typical energized systems include systems used to provide heating, ventilation, cooling, humidification, dehumidification, lighting, hot water heating, interior conveyance, waste handling, and cooking, as well as equipment like typewriters and computers.

Non-Energized Systems

Non-energized systems are those that do not consume energy directly, but do affect the amount of energy that an energized system must expend to get its job done. Typical non-energized systems include walls, windows, floors, roofs, ceilings, doors, and so forth – as well as weather, landscaping, siting, and similar factors.

Human Systems

Human systems refer to people who have an impact on when and in what quantity energy is consumed. These people include staff and visitors.

SYSTEM INTERACTION

If each component of each system functions as efficiently as possible, the absolute minimum amount of energy is required to complete a job. Although this absolute minimum is an ideal that is seldom achieved, it nonetheless stands as the ultimate goal of any energy mangement program.

The interaction of energy systems can be demonstrated with a common example: the automobile. Three methods can be used to reduce the energy consumption of a typical car.

End-Use Restriction

The first method is to drive the car less, an end-use restriction. It is a completely acceptable approach, provided the car is not driven less than it is needed.

Efficiency in Operation

The second method considers the efficiency of driving habits, such as driving the car at 50 mph, avoiding panic stops, pressing the accelerator as if there were an egg between it and the driver's foot, and so on. This relates primarily to human systems and habits, and is similar to turning out lights when they are not needed or closing exterior doors and windows when air conditioning is on.

System Efficiency

The third method ensures that all systems in the car affecting energy consumption operate as efficiently as possible. This requires consideration of end-use restrictions and usage habits covered in the first two methods, as well as a close analysis of other factors that affect energy consumption. The most obvious other factor is the engine. If in tune, the engine runs efficiently. But other systems also are affected. Radial tires generally give better gas mileage than non-radials. Tires inflated to the correct pressure give better mileage than underinflated tires. Tinted glass reduces interior heat gain, which means the air conditioner runs less, consuming less energy. The exterior finish of the car, when waxed and smooth, has less wind resistance than a finish that is comparatively rough. Less wind resistance means the engine has to work less, which means more energy efficiency – more miles per gallon of fuel.

Obviously, the third method is most desirable. It examines all ways in which energy consumption is affected and reveals numerous options — some more effective than others — that can reduce energy consumption. This not only means the potential for more energy savings, but also the ability to choose options that are compatible with available time and budget. Likewise, this is essentially the purpose for which the energy audit is intended.

Although a building is more complicated than a car, basic principles remain the same. Maximum energy savings are achieved by considering all options, the way options affect each other, potential savings versus cost, and many other factors. However, it should be stressed that maximum benefit comes from maximum efficiency. Driving an untuned car less does not make the car more efficient. However, if the car is driven less, driven carefully, and kept in tune, the least amount of energy is consumed every time the car is used.

BUILDING SYSTEM INTERACTION

With these three conservation methods in mind, consider how a building's heating and cooling system is affected by other elements of the three energy systems.

Heating and cooling systems are affected primarily by the factors of heat loss and heat gain. These factors and a few of the many steps that can be taken to reduce their impact are as follows:

Step 1. Infiltration.

- The term "infiltration" refers to the passage of outside air into a building through apertures such as cracks around windows and door jambs, doors and windows left open, and outside air dampers that do not close tightly, to name a few. In winter, infiltration causes heat loss. Outside air that enters the building must be heated to meet desired conditions. During summer, infiltration causes heat gain. The warm air that enters the building must be cooled to meet desired conditions. In many cases, additional energy must be expended to humidify, dehumidify, or filter outside air.

- Energized, non-energized, and human systems all affect infiltration. If a building's air-handling system maintains a positive air pressure in the building – that is, if interior air pressure slightly exceeds exterior pressure – then infiltration is largely eliminated. Non-energized systems also are involved because the condition of the building's exterior envelope, doors, and windows determines the number, size, and location of infiltration access points. Human systems are involved because people are responsible for leaving windows and doors open, as well as for observing, reporting, and correcting deficiencies that cause excessive infiltration

Step 2. Transmission.

- The term "heat transmission" refers to the amount of heat transmitted into or out of a building through the various components of the building envelope – primarily exterior walls, windows, doors, skylights, roof, and floor. The amount of heat loss or gain caused by transmission depends on the difference between indoor and outdoor temperatures and the basic principle of heat flow: heat is always transmitted from an area of higher temperature to an area of lower temperature. Accordingly, during winter, heat flows from the interior to the exterior, through the building envelope. During summer, the process reverses and heat is transmitted from outside to inside.

- The rate of transmission depends on the materials used to construct the building envelope and their resistance to heat flow. This rate can be affected by, among other things, additional insulation or storm windows, especially on parts of the building exposed to the most severe conditions.

Step 3. Ventilation.

- "Ventilation" is the term used to describe the function of the mechanical system that draws in fresh outside air. Ventilation affects heating and cooling systems in the same way that infiltration does, but much more significantly. The rate of ventilation is referred to in terms of cubic feet per minute, or cfm. The greater the cfm, the more heating or cooling required to offset heat loss or heat gain caused by unconditioned air brought into the building. In many instances, the single most effective energy conservation measure — and one achieved with virtually no expense — involves reduction of the ventilation rate.

Step 4. Lighting.

- Lighting contributes to a building's heat gain in direct proportion to the wattage of lamps involved. Heat gain is generally beneficial in winter months because it provides heat that otherwise would have to be provided by mechanical heating systems. In summer months, of course, the mechanical cooling system must work harder to compensate for heat gain from light sources. There are many techniques available to modify the heating characteristics of lighting systems, while keeping them consistent with the need for proper illumination. Several of the techniques involve human systems — the efficiency of how people use, or do not use, lighting.

Step 5. Solar heat.

- Solar heat, like the heat of light, contributes to heat gain throughout the year. The specific effect of solar heat depends on the geographical area involved, the intensity and direction of the rays, the materials that comprise the building envelope, the color and texture of walls, the extent and type of solar controls, and other factors. Many non-energized systems — such as blinds and drapes — can be used to minimize the effect of solar heat gain. In many cases, the effectiveness of human systems (e.g., closing the drapes at the correct time) will determine how well the non-energized systems works.

Step 6. Equipment.

- Virtually all energized devices, including business machines, coffee makers, printing presses, television sets, and so forth, contribute to heat gain. In some cases, this heat, or portions of it, can be recovered from one part of a building where heat is not needed and be ducted to another part of a building that requires heat.

Step 7. Occupants.

- People contribute to heat gain whenever the room temperature falls below their body temperature. People also affect the moisture content of air through perspiration and exhalation. The way in which different types of spaces are used determines the extent of heat gain from occupants.

- In almost all cases, undesirable heat loss and heat gain can be reduced, often significantly. Modification to fundamental systems can reduce the load placed on heating and cooling equipment and thereby reduce the energy required for the equipment's operation.

Any modification must consider the human element. But individual comfort need not be severely affected while substantial savings are attained.

ENERGY USE CHARACTERISTICS

It is not an indictment of operations and maintenance personnel to state that almost all buildings — publicly and privately-owned — are enormous energy wasters. Savings of at least 15% should be easily realized with little or no capital cost. Other improvements will usually provide another 15-20% or more, depending on many factors — but at greater cost. Improvements that are costly are usually selected on the basis of how quickly energy savings pay for the improvements.

Residential, commercial, and industrial buildings are designed for specific purposes. Schools, hospitals, local government, and public care buildings serve a variety of purposes. Buildings can include the following types:

- general office buildings
- warehouses
- jails/police facilities
- fire stations
- motor pools
- utility buildings
- special treatment centers
- primary and secondary schools
- colleges and universities
- nursing homes
- others

All building types have different primary purposes and construction. Generally, however, each has energy-using characteristics that can be categorized into four major systems: HVAC, lighting, building envelope, and ancillary systems. A fifth system, process energy, is limited to industrial applications. Later sections describe some important aspects of these systems, and these descriptions are helpful in understanding the recommendations contained throughout the energy audits course material. The relative use of energy by systems varies according to the type of building and intended building uses. For example, consider the following building types and uses in relation to energy use:

SCHOOLS

In 1977, the nation's educational institutions consumed 1.1 quadrillion Btus, or approximately 1.5% of the total U.S. consumption of energy of all forms. As energy costs continue to erode educational budgets, the importance of a comprehensive energy management program for educational institutions becomes obvious.

As can be seen from Figure 1, energy is utilized in a number of ways. Although these percentages will vary, the heating, ventilating, and air conditioning systems (HVAC) usually represent the greatest single usage. Lighting and general electrical energy consumption represent the second major category.

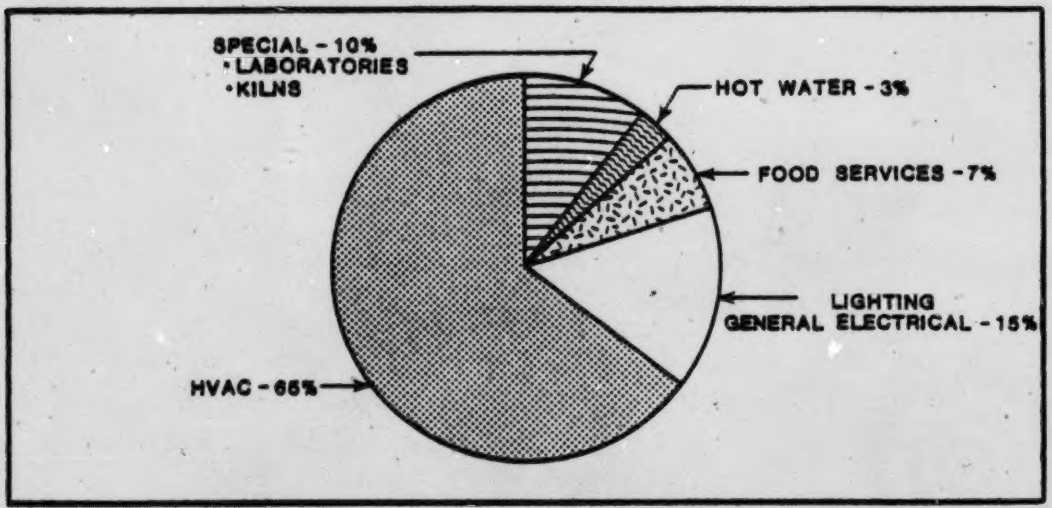


Figure 1. Major Energy Uses in a Typical U.S. Educational Institution.

HOSPITALS

Nearly 90% of all U.S. hospitals were designed and constructed before 1974, when the importance of effective energy management was beginning to surface.

As is shown in Figure 2, environmental control (heating, ventilating, and air conditioning) requires the greatest share of all energy used in a typical hospital; lighting and wall receptacles often represent the second highest end-use.

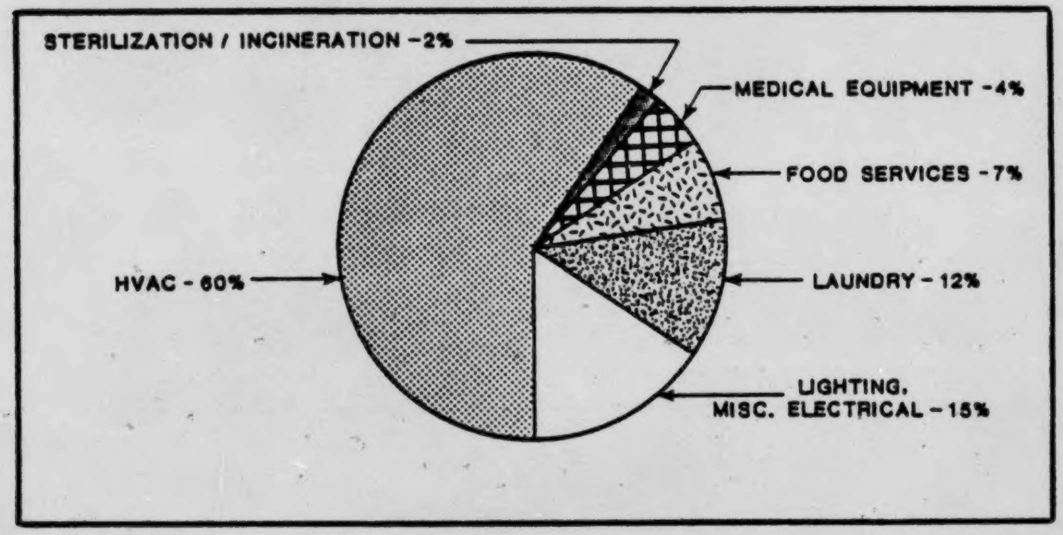


Figure 2. Major Energy Uses in a Typical U.S. Hospital.

PUBLIC BUILDINGS

Although consumption percentages vary with building function and location (climate), Figure 3 illustrates major energy uses of a typical office building. Again, space conditioning represents the area of highest consumption.

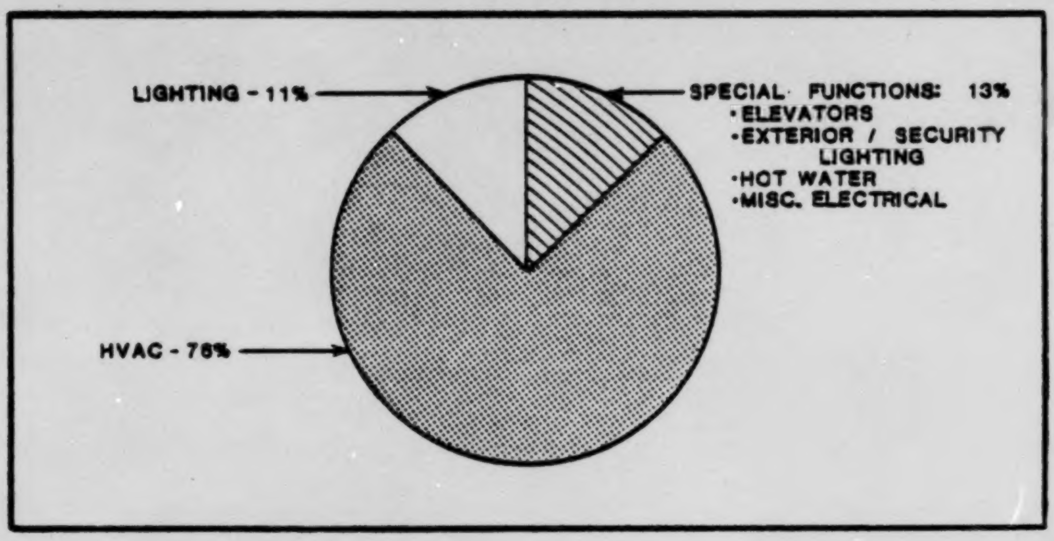


Figure 3. Major Energy Uses in a Typical U.S. Office Building.

(Energy uses for other types of local government buildings, such as warehouses, jails, and so forth, are not available.)

LONG-TERM PUBLIC CARE FACILITIES

Public care facilities such as nursing homes, which have not implemented comprehensive energy management programs, usually exhibit energy consumption patterns that are comparable to those of other buildings of a similar type, size, use, or location. It is not unusual to discover total energy consumption in the range of 300,000 to 360,000 Btus per gross square foot per year, especially in the cooler climate zones.

Figure 4 indicates typical energy uses for a nursing home facility. Notice that space heating, cooling,

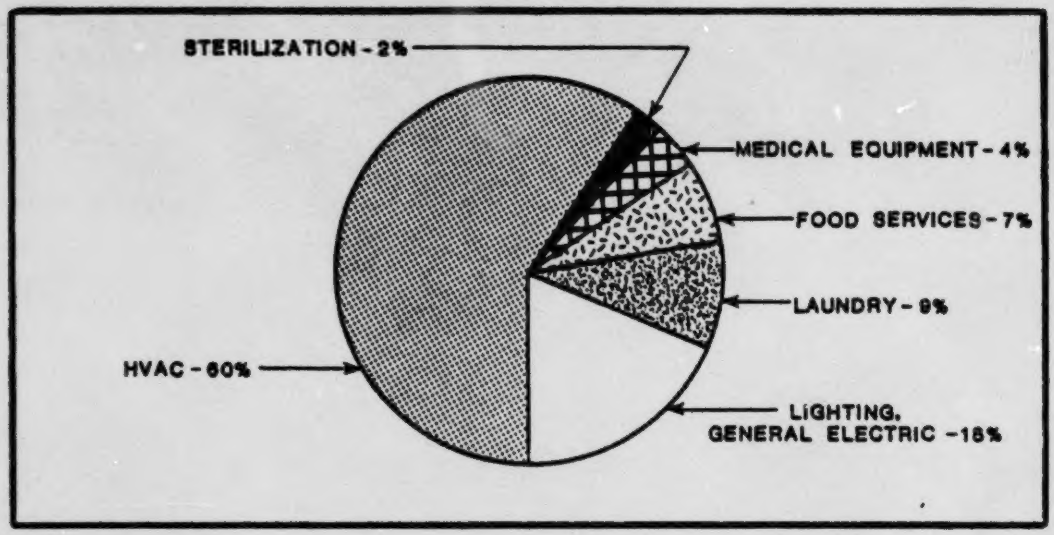


Figure 4. Major Energy Uses in a Typical U.S. Nursing Home.

ventilation, and lighting contribute to over three-fourths of the total consumption of the facility. These areas, then, represent major energy conservation opportunities.

COMMERCIAL BUILDINGS

Figure 5 shows the energy-use patterns of typical table service restaurants and fast food restaurants. It is important to note that, while HVAC systems consume much of the energy used in restuarants, roughly the same amount of energy is needed to prepare and store food. Thus, in addition to conservation opportunities in the HVAC and lighting systems of restaurants, there is considerable potential for energy conservation in the processes associated with food preparation.

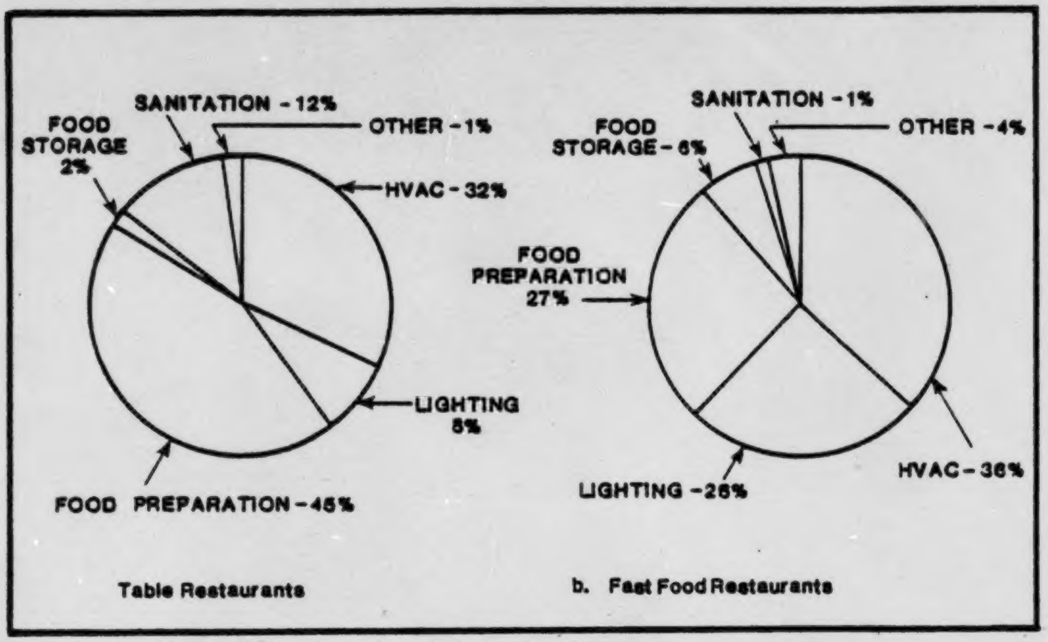


Table Restaurants

b. Fast Food Restaurants

Figure 5. Major Energy Uses in Typical U.S. Restaruants.

In retail stores, as is indicated in Figure 6, the greatest potential for energy conservation is found in lighting systems. HVAC systems offer the second most important opportunity for energy-efficiency modifications in retail establishments, although the HVAC system typically uses only about half as much energy as does the lighting system.

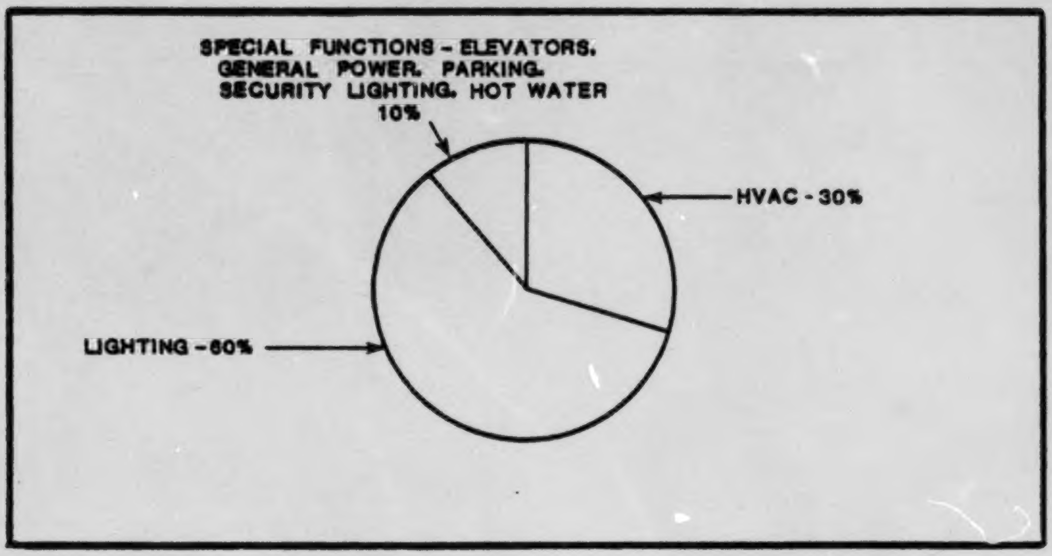


Figure 6. Major Energy Uses in a Typical U.S. Retail Store.

RESIDENCES

Figure 7 shows energy end-use patterns of apartment buildings. In both apartments and single-family dwellings, environmental control (HVAC) accounts for a majority of the energy consumed. Thus, the major energy conservation opportunities to be found in residential structures are in improving the efficiency of HVAC equipment, reducing air infiltration and exfiltration, and reducing undesirable heat gain and loss.

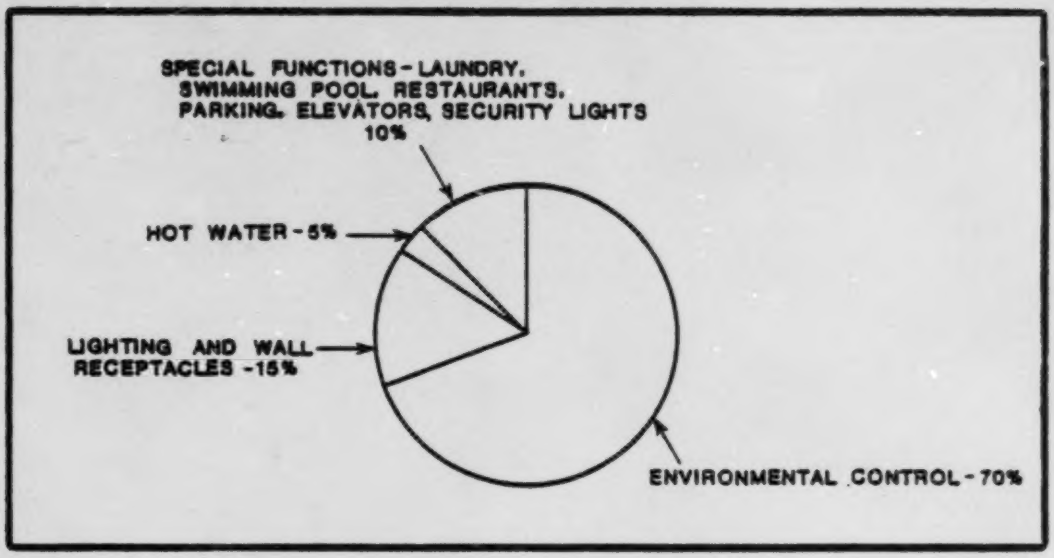


Figure 7. Major Energy Uses in a Typical U.S. Apartment Building.

INDUSTRIAL APPLICATIONS

Specific energy-use patterns will vary drastically from one industrial application to the next. Figure 8, therefore, should be viewed only as an example of how a die-casting plant uses energy for its particular processes.

In general, however, the energy use of many industries does correspond roughly to the model of 30% for housekeeping and 70% for processes (as is shown in the outer circle of Figure 8). Thus, the greatest energy conservation opportunities in industrial applications frequently will be found in modifying processes and process equipment.

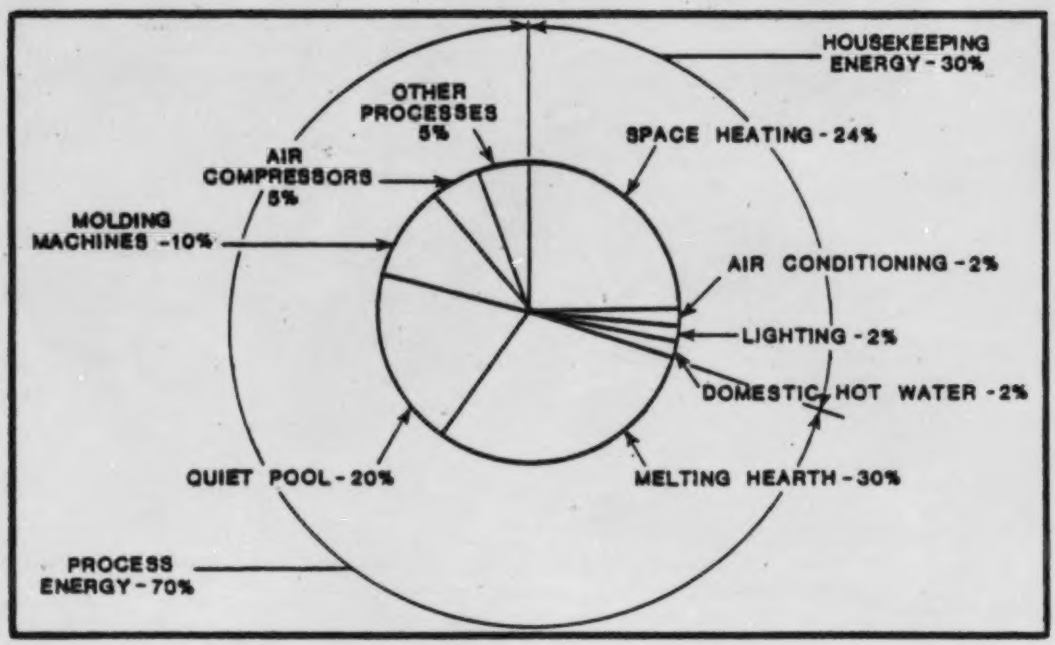


Figure 8. Major Energy Uses in a Typical U.S. Die-Casting Plant.

UNDERSTANDING ENERGY BILLINGS

The first step in any energy audit is to review all utility bills for the past few years. This may or may not uncover some discrepancies, but it will provide a better understanding of energy billings and indicate where and how energy is consumed in the buildings.

BILL CHARGES

In most cases a bill will include charges for the following:

Energy

Most electric utilities use a declining sliding block approach for the energy charge: that is, so much per kilowatt-hour (kWh) for the first 1000 kWh; so much per kWh for the second 1000 kWh; and so on. In most cases, the more kWh consumed, the lower the cost per kWh.

Customer-Related

Some utilities add what are called customer-related costs. These comprise a special charge that reflects part of the distribution investment, part of the operating and maintenance cost, the cost of accounting and collection, and so on. This is generally included in the utility company's base rate.

Demand

The demand charge is designed to make the customer pay an appropriate share of the utility's fixed investment in the production, transmission, and distribution equipment required to meet the customer's maximum requirements. The charge is based on the rate of electricity consumption. The more energy used at any given time, the larger the utility company's investment in generation, transmission, and distribution systems has to be. For example, consider two users: A and B, both consuming an equal number of kWh each day. User A consumes electric energy 24 hours a day and user B consumes it 8 hours a day. User B requires the utility to have generating and distribution capacity three times the capacity required to serve user A during the 16 hours per day that B is not operating. Therefore, user B is billed for this extra investment.

The consumer's actual demand is computed as the average amount of energy consumed in a predetermined time interval — usually 15, 30, or 60 minutes. Regardless of the interval, the highest demand recorded during a month is considered the actual demand for the month.

LOAD FACTOR

The effectiveness with which energy is used is rated in terms of load factor:

$$\text{Load} = \frac{\text{Energy Used(in kWh)}}{\text{Highest Demand(in kW)}} \times \frac{1}{\text{Time}} \text{ (720 hours, usually).}$$

Equation 1

Example A shows the methodology for calculating load factor.

EXAMPLE A: LOAD FACTOR CALCULATION.

Given: Electricity consumption in a 30-day period – 700,000 kWh
Peak demand – 1500 kWh
Find: Load factor.
Solution: $\frac{700,000 \text{ kWh}}{1500 \text{ kW}} \times \frac{1}{720 \text{ hrs}} = 64.8\%$ load factor

In essence, the lower the established demand, the higher the load factor; the higher the load factor, the lower the relative cost for electric service.

The techniques used most often to improve load factor are demand management and demand control. The two are not synonymous terms. Demand control refers to the electromechanical procedure of load shedding. Demand management encompasses demand control and other activities that can help reduce demand charges even more.

LOW POWER FACTOR PENALTY

Another charge sometimes applied is a penalty for low power factor. The power that must be supplied to any induction load – such as induction motors, transformers, fluorescent lamps, and so forth – is made up of real and reactive power.

Real power, or the working power, is measured in kilowatts (kW). Reactive power, or magnetizing current, is required to produce the flux necessary for the operation of any induction equipment. Without magnetizing current, energy could not flow through the core of a transformer or across the gap of an induction motor. The unit used to measure reactive power is the kilovar, or kvar.

The vector sum – not the arithmetical sum – of the real power and the reactive power is the apparent power, measured in kilovolt-amperes, or kVA.

Power factor is a ratio of real power (kW) to apparent power (kVA), and it is calculated as is shown in Equation 2.

$$\text{Power Factor} = \frac{\text{Real Power (kW)}}{\text{Apparent Power (kVA)}} \qquad \text{Equation 2}$$

Electric utilities must provide both real and reactive power for their customers. Reactive power does not register on a kilowatt hour meter. Still, producing it requires the utility to put additional investment into generating, transmission, and distribution facilities.

Many utilities make up for the expense of producing reactive power by including power factor provisions in their rates. In practice, many utilities define low power factor as anything less than 0.9.

Some power factor improvement will prove worthwhile if electric use meets one or more of the following conditions:

- power demand is recorded on the bill (in kVA);
- electric rate has a kvar or power factor penalty clause;
- there are problems with voltage regulation or chronic low voltage; or
- load growth limits capacity and more capacity is needed.

One typical cause for low power factor is lightly loaded motors; such motors can draw an excessive amount of reactive power and increase energy losses in the overall distribution system. Power factor can be corrected by the installation of capacitors. It is advisable to review the need for and amount of power factor correction on specific types of loads with either the utility, equipment manufacturer, or a consultant.

TIME OF DAY

Discounts are allowed for electrical usage during off-peak hours in some service areas. Energy users who can reschedule their demand for electricity, such as some manufacturing plants, can take advantage of the lower rates.

RATCHET RATE

The billing demand is based on 80-90% of peak demand for any one month. The billing demand will remain at that ratchet for 12 months, even though actual demand during succeeding months may be less.

DETERMINING HOW MUCH ENERGY IS USED

The only way to determine whether energy and dollars are being saved is to keep accurate records. Utility bills and meters are the best sources of information for those records. The purpose of this section is to explain how to interpret utility bills and how to organize that information into a useful form.

Figures 9 and 11 illustrate how to record gas and electric utility bill data onto energy data sheets. Figure 10 demonstrates how to record one month's electricity bill information. The next time period's data are recorded on the next line. (If utility bills from several past years are available, it is wise to select a base line year, such as 1975 or 1976, to which current usage can be compared.)

Figure 12 explains how to record gas bill data. The same type of information can be recorded for other types of fuel sources on separate data sheets.

After recording the final month's fuel consumption, separate monthly fuel consumptions should be added. Total annual consumption should be recorded in the total row.

Two conversion factors are used for both electricity and steam consumption. The larger figures indicate the values to be used in reporting in compliance with the April 2, 1979, Federal Register, Part VI, Department of Energy, Energy Measures and Energy Audits Grant Programs for Schools and Hospitals and Buildings Owned by Units of Local Government and Public Care Institutions: Section 450.42(a)(11). These larger figures represent source or point of generation values, and include transmission losses and production inefficiencies.

ENERGY DATA FORM

	A		B		C		D		E		F		G	
Month	Reading Date		kWh Used		Measured Demand kW		$ Cost		(FCA) Fuel Cost Adjustment ($)		Total Cost D + E = F		$/kWh F ÷ B = G	
	From	To	Current	Base	Current	Base	Current	Base	Current	Base	Current	Base	Current	Base
Jan														
Feb														
Mar														
Apr														
May														
Jun														
Jul														
Aug														
Sep														
Oct	10-19	11-20	28080		110.40		$1,135.01		$ 18.06		$1.153.07		.04	
Nov														
Dec														

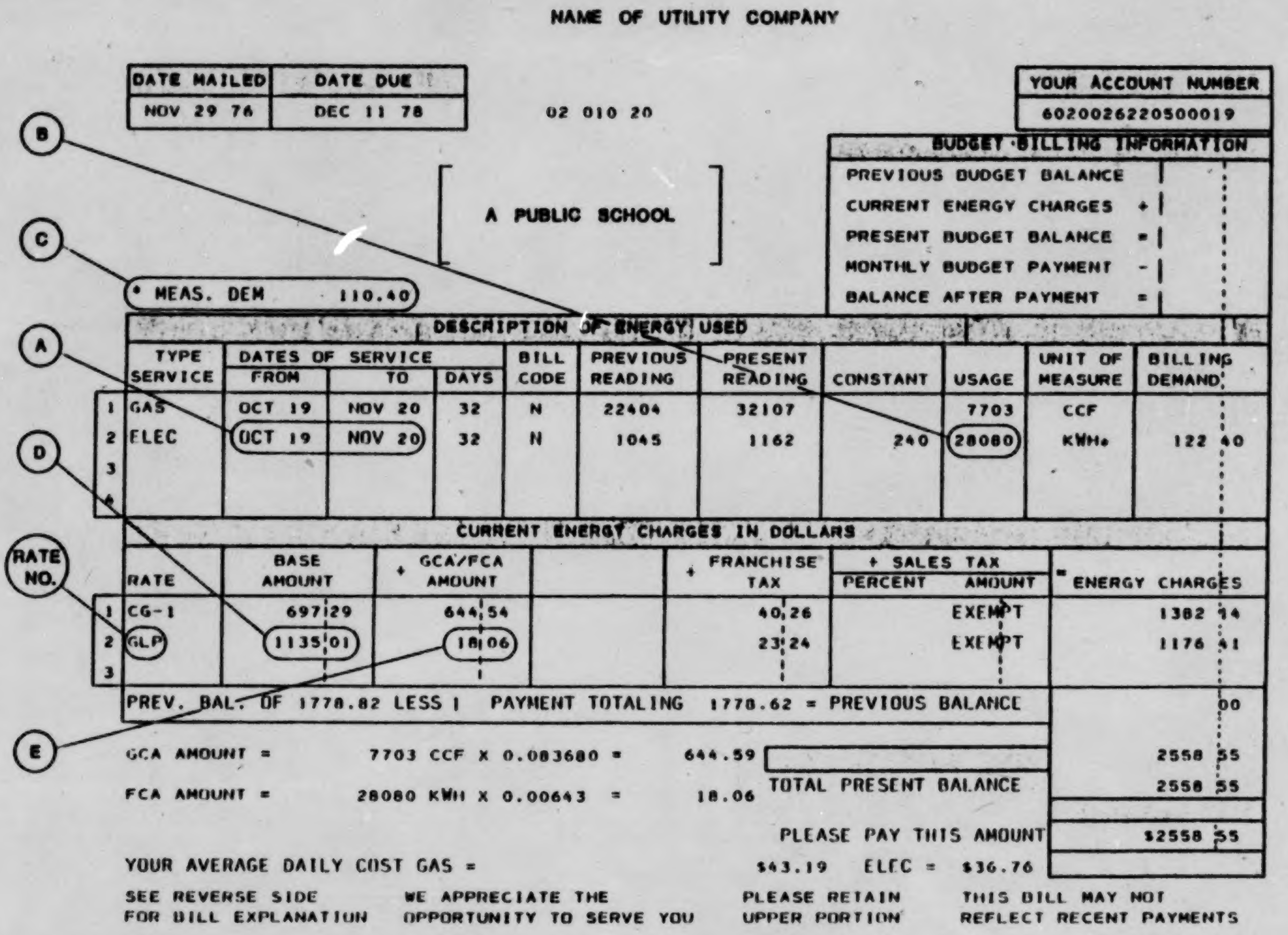
Column B Totals		
On-Site Btu Conversion Factor	x 3,413	x 3,413
Total Btus		
Column B Totals		
Point of Generation Btu Conversion Factor	x 11,600	x 11,600
Total Btus		

ELECTRICTY ____________ kWh/yr

Electricty Rate No QLP

Building A PUBLIC SCHOOL

Figure 9. How to Record Electricity Bill Data.


B
C
A
D
RATE NO.
E

NAME OF UTILITY COMPANY

DATE MAILED	DATE DUE
NOV 29 76	DEC 11 78

02 010 20

YOUR ACCOUNT NUMBER
6020026220500019

A PUBLIC SCHOOL

BUDGET BILLING INFORMATION	
PREVIOUS BUDGET BALANCE	
CURRENT ENERGY CHARGES +	
PRESENT BUDGET BALANCE =	
MONTHLY BUDGET PAYMENT -	
BALANCE AFTER PAYMENT =	

* MEAS. DEM 110.40

DESCRIPTION OF ENERGY USED

	TYPE SERVICE	DATES OF SERVICE FROM	TO	DAYS	BILL CODE	PREVIOUS READING	PRESENT READING	CONSTANT	USAGE	UNIT OF MEASURE	BILLING DEMAND
1	GAS	OCT 19	NOV 20	32	N	22404	32107		7703	CCF	
2	ELEC	OCT 19	NOV 20	32	N	1045	1162	240	28080	KWH.	122 40
3											
4											

CURRENT ENERGY CHARGES IN DOLLARS

	RATE	BASE AMOUNT	+ GCA/FCA AMOUNT		+ FRANCHISE TAX	+ SALES TAX PERCENT	AMOUNT	= ENERGY CHARGES
1	CG-1	697 29	644 54		40 26		EXEMPT	1382 14
2	GLP	1135 01	18 06		23 24		EXEMPT	1176 41
3								

PREV. BAL. OF 1778.82 LESS 1 PAYMENT TOTALING 1778.62 = PREVIOUS BALANCE	00
GCA AMOUNT = 7703 CCF X 0.083680 = 644.59	2558 55
FCA AMOUNT = 28080 KWH X 0.00643 = 18.06 TOTAL PRESENT BALANCE	2558 55
PLEASE PAY THIS AMOUNT	$2558 55
YOUR AVERAGE DAILY COST GAS = $43.19 ELEC = $36.76	

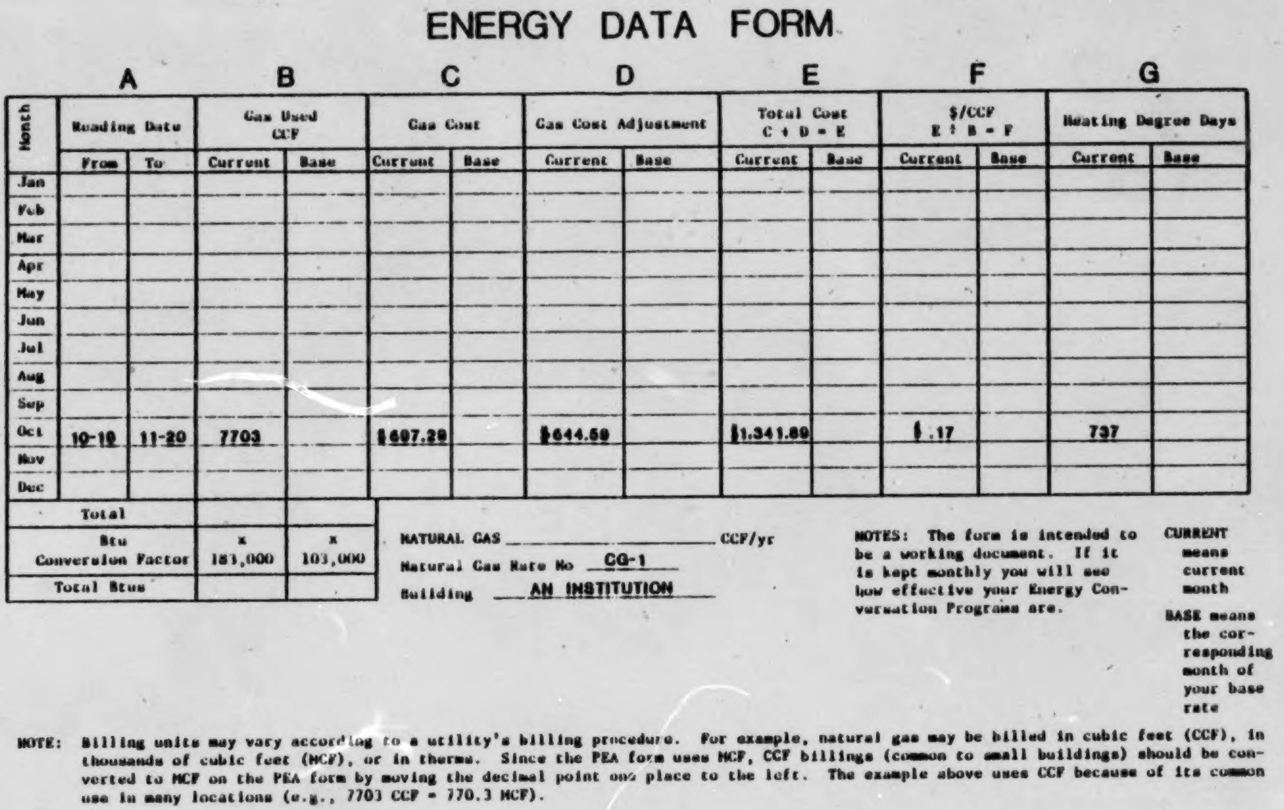
SEE REVERSE SIDE FOR BILL EXPLANATION

WE APPRECIATE THE OPPORTUNITY TO SERVE YOU

PLEASE RETAIN UPPER PORTION

THIS BILL MAY NOT REFLECT RECENT PAYMENTS

Figure 10. Typical Utility Bill With Electricity Use Highlighted.



ENERGY DATA FORM

	A		B		C		D		E		F		G	
Month	Reading Date		Gas Used CCF		Gas Cost		Gas Cost Adjustment		Total Cost C + D = E		$/CCF E ÷ B = F		Heating Degree Days	
	From	To	Current	Base	Current	Base	Current	Base	Current	Base	Current	Base	Current	Base
Jan														
Feb														
Mar														
Apr														
May														
Jun														
Jul														
Aug														
Sep														
Oct	10-19	11-20	7703		$697.29		$644.59		$1,341.89		$ .17		737	
Nov														
Dec														

Total		
Btu Conversion Factor	x 103,000	x 103,000
Total Btus		

NATURAL GAS ______________ CCF/yr

Natural Gas Rate No CG-1

Building AN INSTITUTION

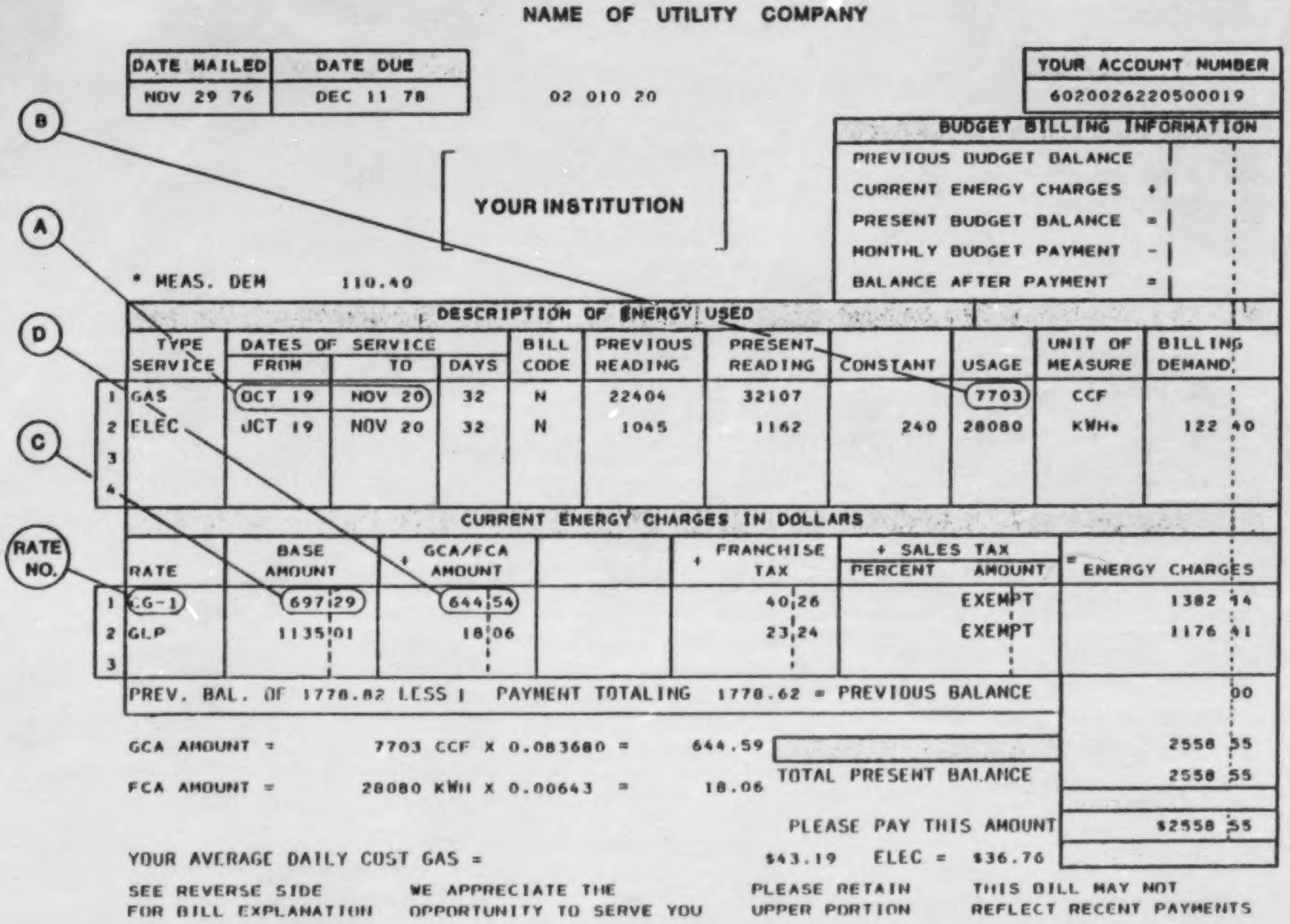
NOTES: The form is intended to be a working document. If it is kept monthly you will see how effective your Energy Conservation Programs are.

CURRENT means current month

BASE means the corresponding month of your base rate

NOTE: Billing units may vary according to a utility's billing procedure. For example, natural gas may be billed in cubic feet (CCF), in thousands of cubic feet (MCF), or in therms. Since the PEA form uses MCF, CCF billings (common to small buildings) should be converted to MCF on the PEA form by moving the decimal point one place to the left. The example above uses CCF because of its common use in many locations (e.g., 7703 CCF = 770.3 MCF).

Figure 11. How to Record Gas Bill Data.


B
A
D
C
RATE NO.

NAME OF UTILITY COMPANY

DATE MAILED	DATE DUE
NOV 29 76	DEC 11 78

02 010 20

YOUR ACCOUNT NUMBER
6020026220500019

YOUR INSTITUTION

BUDGET BILLING INFORMATION	
PREVIOUS BUDGET BALANCE	
CURRENT ENERGY CHARGES +	
PRESENT BUDGET BALANCE =	
MONTHLY BUDGET PAYMENT −	
BALANCE AFTER PAYMENT =	

* MEAS. DEM 110.40

DESCRIPTION OF ENERGY USED

	TYPE SERVICE	DATES OF SERVICE FROM	TO	DAYS	BILL CODE	PREVIOUS READING	PRESENT READING	CONSTANT	USAGE	UNIT OF MEASURE	BILLING DEMAND
1	GAS	OCT 19	NOV 20	32	N	22404	32107		7703	CCF	
2	ELEC	OCT 19	NOV 20	32	N	1045	1162	240	28080	KWH*	122 40
3											
4											

CURRENT ENERGY CHARGES IN DOLLARS

	RATE	BASE AMOUNT	+ GCA/FCA AMOUNT		+ FRANCHISE TAX	+ SALES TAX PERCENT	AMOUNT	= ENERGY CHARGES
1	G-1	697 29	644 54		40 26		EXEMPT	1382 14
2	GLP	1135 01	18 06		23 24		EXEMPT	1176 41
3								

PREV. BAL. OF 1778.82 LESS 1 PAYMENT TOTALING 1778.62 = PREVIOUS BALANCE 00

GCA AMOUNT = 7703 CCF X 0.083680 = 644.59 — 2558 55

FCA AMOUNT = 28080 KWH X 0.00643 = 18.06

TOTAL PRESENT BALANCE 2558 55

PLEASE PAY THIS AMOUNT $2558 55

YOUR AVERAGE DAILY COST GAS = $43.19 ELEC = $36.76

SEE REVERSE SIDE FOR BILL EXPLANATION — WE APPRECIATE THE OPPORTUNITY TO SERVE YOU — PLEASE RETAIN UPPER PORTION — THIS BILL MAY NOT REFLECT RECENT PAYMENTS

Figure 12. Typical Utility Bill With Gas Use Highlighted.

The smaller of the conversion factors for electricity and steam is used for institutional record keeping, since these reflect on-site consumption. These factors are standard conversions and are not adjusted for altitude.

Although utility bill formats may be different from those shown in Figures 10 and 12, contents are the same. Any questions about utility bill information can be answered by the local utility company.

DEVELOPING ENERGY CONSUMPTION DATA

A form like the one in Figure 13 can be used to log energy consumption data. In addition to supplying data for the energy audit, such forms can be used to develop an Energy Utilization Index (EUI). The EUI is a reference which reduces all forms of energy used (electricity, oil, gas, etc.) to one common base (British Thermal Units, or Btus) and divides that total by the total number of gross conditioned square feet in the building. Example B demonstrates EUI calculation.

The EUI is most useful as reference that quickly shows changes in overall energy consumption from month to month, year to year, one month of one year to the same month in the following year, and so forth. The EUI also facilitates comparisons between similar buildings, making it easy to determine which buildings are most energy efficient. A chart like the one that appears in Figure 14 can be used to compare EUIs.

ENERGY USE IN BTUS PER SQUARE FOOT

Month	Electricity						Natural Gas				Oil				Other				Total Energy		
	Consumption		Demand		Cost				Cost				Cost				Cost				
	kWh	Mil Btu	Actual	Billed	Total	Per kWh	MCF	Mil Btu	Total	Per MCF	Gal	Mil Btu	Total	Per Gal	Unit	Mil Btu	Total	Per Unit	Mil Btu	Total Cost	Btu Per Sq Ft*
Jan																					
Feb																					
Mar																					
Apr																					
May																					
Jun																					
Jul																					
Aug																					
Sep																					
Oct																					
Nov																					
Dec																					
Total																					

multiply kWh x 0.0116 = MMBtu

multiply MCF x 1.03 = MMBtu

*Note: Btu per Sqaure Foot: Divide total energy Btu by number of square feet of conditioned (heated and/or cooled) space in building or facility metered for gas and electricty.

TOTAL ENERGY (in MMBtu) ________________

Gross Conditioned square feet* of ________

= ________ MMBtu/Sq Ft/Yr

** = EUI of _____ Btu/Sq Ft/Yr

**Remember to move decimal point of million Btu figure six places to the right to convert MMBtu/GSF/yr to Btu/GSF/yr.

Figure 13. Energy Consumption Log.

EXAMPLE B: CALCULATING THE ENERGY UTILIZATION INDEX.

Given:

Total gross conditioned floor area	742,000 sq ft
Total electricity consumption	1131 x 10^3 kWh
Total natural gas consumption	1742 MCF (MCF = thousand cubic feet)
Btu/kWh	3412
Btu/CF	1030

Find: Energy Utilization Index.

Solution: Convert electricity consumed to Btus:

$$1131 \times 10^3 \text{ kWh} \times 3412 \text{ Btu/kWh} = 3.86 \times 10^9 \text{ Btu}$$

Convert natural gas consumed to Btus:

$$1742 \times 10^3 \text{ CF} \times 1030 \text{ Btu/CF} = 1.8 \times 10^9 \text{ Btu}$$

Find the number of Btus per square foot of gross conditioned floor area (the EUI):

$$\frac{(3.86 \times 10^9) + (1.8 \times 10^9) \text{ Btu}}{742{,}000 \text{ sq ft}} = 7.63 \times 10^3 = 7630 \text{ Btu/sq ft}$$

EUI COMPARISON CHART

(would be completed by using monthly Btu usage from Energy Consumption Record, such as in Figure 13)

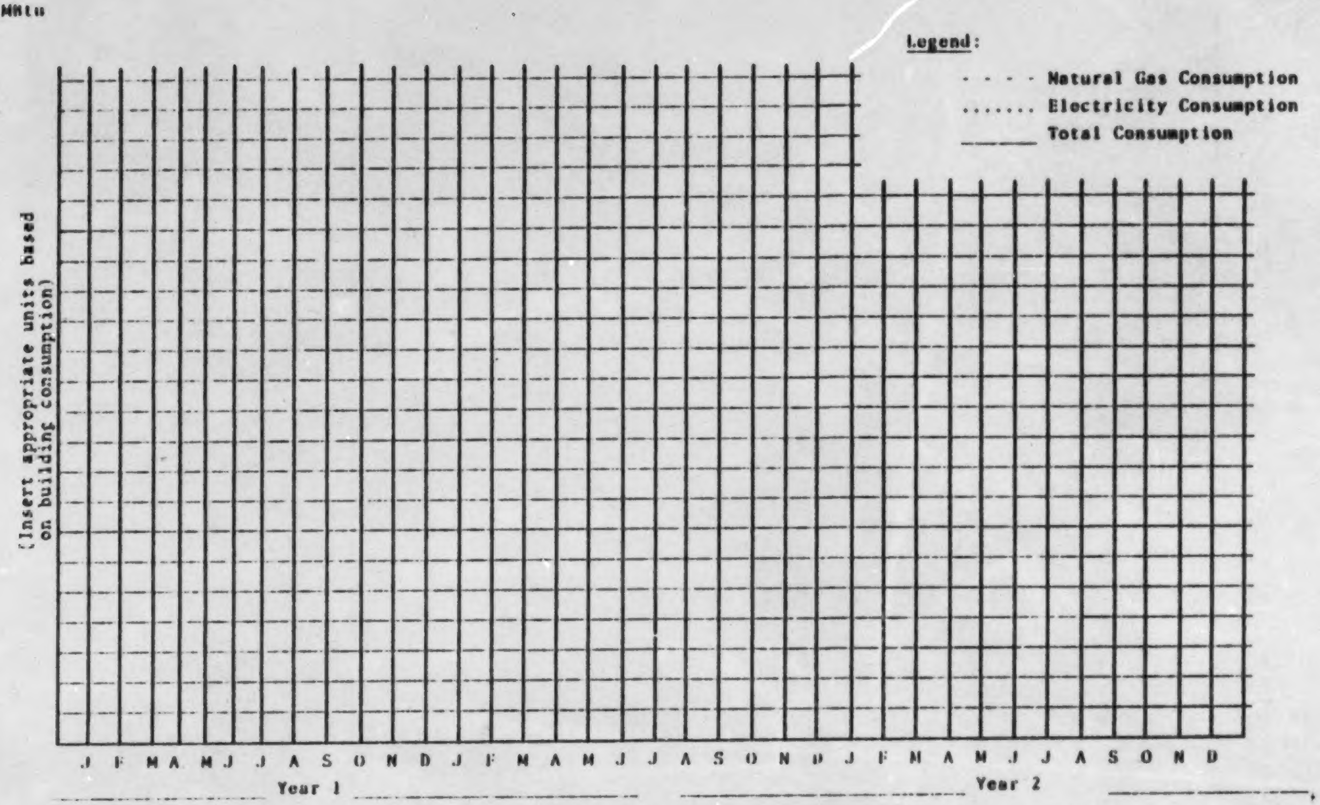


Figure 14. EUI Comparison Chart.

EXERCISES

1. Define the following terms as they relate to building energy use:
    a. Energized systems
    b. Non-energized systems
    c. Human systems
2. Define each of the following in relation to building energy use, and give at least one example of how each affects building energy consumption:
    a. Infiltration
    b. Transmission
    c. Ventilation
    d. Lighting
    e. Solar heat
    f. Equipment
    g. Occupants
3. What are the four major energy-using systems?
4. List and describe the three typical utility bill charges.
5. Discuss the problem in electric utility billing for reactive power.
6. What is the methodology for developing an Energy Utilization Index?

REFERENCES

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Energy Audit Workbook for Die-Casting Plants. Fuel and Energy Consultants, Inc., 1978.

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Energy Audit Workbook for Restaurants. Fuel and Energy Consultants, Inc., 1978.

Energy Audit Workbook for Retail Stores. Fuel and Energy Consultants, Inc., 1978.

Energy You Can Bank On. Colorado Energy Conservation and Alternatives Center for Commerce and Industry, 1978.

Practical Energy Management in Health Care Institutions. Blue Cross of Greater Philadelphia, July, 1978.

Total Energy Management for Hospitals. Hyattsville, MD: Department of Health, Education, and Welfare, Publication No. 78-613, 1978.

TEST

Multiple Choice.

1. Real power is measured in ...
   - a. kVA
   - b. kWA
   - c. kHw
   - d. kWh
2. Given an energy consumption of 500,000 in a 30-day period, during which the peak demand was 1800 kW, what is the load factor?
   - a. 62.1%
   - b. 30.2%
   - c. 38.5%
   - d. 49.6%
3. Convert the following data into an Energy Utilization Index for a one-month period:

Total gross conditioned floor area	909,000 sq ft
Total electricity consumed ...	1624 x 10^3 kWh
Total natural gas consumed ...	2102 MCF
Btu/kWh	3412
Btu/CF	1030

The EUI is ...

- a. 9269 Btus/sq ft.
- b. 8438 Btus/sq ft.
- c. 8984 Btus/sq ft.
- d. 7431 Btus/sq ft.

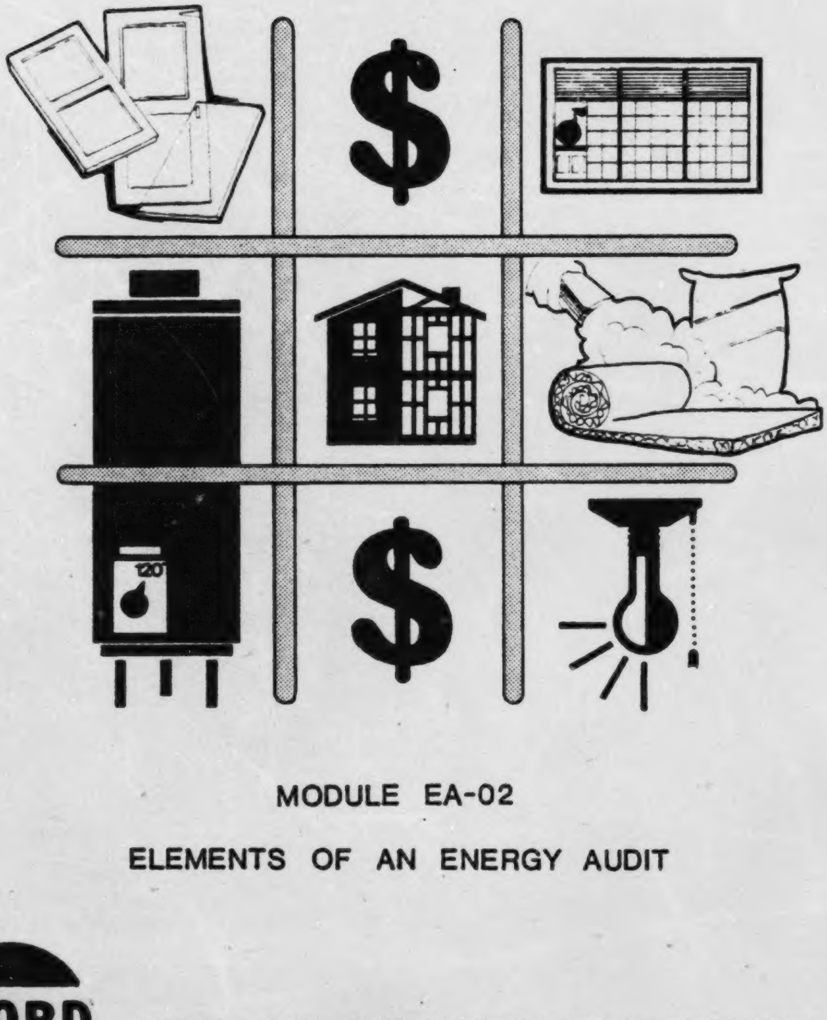
Enter true or false in the blank after the statements in Items 4-10.

4. Apparent power is the arithmetic sum of real power and reactive power. __________
5. The EUI has only one base energy unit. __________
6. The greatest opportunity for conserving energy in residences is related to environmental control system load. __________
7. Although a building is more complicated than a car, end use restriction is still the most effective way to conserve energy without reducing the amount of work done or the comfort of the occupants. __________
8. Load factor is rated in kilovolt-amperes. __________
9. The main distinction between the walk-through audit and the mini-audit is that the walk-through audit calculates the economics of making recommended energy-efficiency improvements. __________
10. Conversion factors used for institutional record keeping are larger than those used for point of generation values, since they reflect on-site consumption, transmission losses, and production efficiencies. __________

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY AUDITS



MODULE EA-02

ELEMENTS OF AN ENERGY AUDIT

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

This module covers the relationship between formal energy auditing and total energy management. Thorough coverage is given to: energy audit theory and performance; energy auditing tools and instruments; the magnitude of savings that can be expected from particular energy conservation measures; and procedures for calculating simple payback and life-cycle costing.

PREREQUISITES

The student should have completed Module EA-01, "Total Energy Management."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Describe the interrelationships between energy auditing and fundamental building systems.
2. List and discuss steps of pre-audit preparation.
3. Describe and use auditing tools and instruments.
4. Calculate simple payback and life-cycle costing.

THE ENERGY AUDIT

Those directing and performing an energy audit must be well-prepared. Usually, the level of expertise required is marginally proportionate to the complexity of the systems involved.

One key to survey accuracy is objectivity. One problem that develops when in-house personnel are involved in energy auditing is a tendency – whether conscious or subconscious – to downplay deficiencies that might make an in-house employee uncomfortable. Thus, the professional auditor/energy conservation expert – with expertise in energy management and an objective approach to the audit – can audit more effectively, accurately, and efficiently than can an individual with day-to-day responsibility for a building's operation.

The energy auditor should obtain a copy of the architectural, mechanical, and electrical design drawings and specifications. The auditor should also become familiar with the building's configuration and design – as well as the building's electrical and mechanical systems and equipment layout, operation, and control. If drawings of these systems are unavailable, the auditor should develop single-line diagrams of existing mechanical and electric systems.

The auditor also should be given operating and maintenance procedures manuals supplied by equipment manufacturers or original building design professionals.

In addition, the auditor should be familiar with utility rate schedules, as well as materials that relate to planned building modernization programs.

Once the surveyor becomes familiar with building systems and equipment data, the next step is to conduct a walk-through survey. Tools required for this task are writing implements and paper — although a tape recorder may be a valuable substitute (especially for interviews with selected personnel). Instruments that may be helpful (but are not generally required for the energy audit) include a light meter, a thermometer, and a 3/4" x 12" steel measuring tape.

PERFORMING THE ENERGY AUDIT

Table 1 lists the steps taken, approximate time required, and appropriate individuals who can perform each step of the energy audit.

TABLE 1. STEPS OF THE ENERGY AUDIT.

Steps	Performed By	Approximate Time Needed For Small To Average Building*
Preliminary Energy Audit		
1. Collect utility bills.	Utility company and/or clerical personnel	1 or 2 days (elapsed time)
2. Review blueprints and plans, determine square footage, location of major equipment, etc.	Auditor	1 – 2 hours
3. Convert utility usage to Btus/sq ft/year.	Auditor	1/2 hour
4. Complete all energy use data, building name, location, etc.	Auditor	2 – 4 hours
5. Complete preliminary building energy analysis.	Engineer, architect, or building personnel familiar with building characteristics	3 – 6 hours
Energy Audit		
6. Conduct walk-through, check HVAC, lighting, envelope, ancillary equipment and renewable resource potential in order or simultaneously. The O&M checklist included in the Energy Audit Workbook or similar checklists should be used.	Auditor (one or two assistants to record findings, if possible)	3 – 6 hours for small to average size building (10,000 to 24,000 sq ft)
7. Make recommendations and complete energy audit forms.	Auditors/assistants	8 – 16 hours

*10,000 – 30,000 square feet

ENERGY AUDITING INSTRUMENTS

Although simple audits may require no more equipment than paper, pencil, calculator, and tape measure, thorough audits of complex building energy systems may require the auditor to use simple thermometers and smoke pellets — as well as advanced electronic devices like infrared scanners. The energy auditor should be familiar with the instruments necessary for the following measurements. A brief description of each instrument is given.

- Temperature Measurement

  Thermometers: Thermometer type used is determined by cost, durability, and application. For air conditioning, ventilation, and hot water system auditing (temperature range: 50° to 250°F), a multi-purpose, battery-operated, three-probe thermometer is necessary. A dial thermometer is used for boiler and oven stack temperature measurement (1000°F) and thermocouples are used to measure very high temperatures (over 1000°F).

  Surface Pyrometer: A surface pyrometer measures the temperature of surfaces. Its probe must usually touch the surface for a reading to be made. Pyrometers measure heat loss through walls and test steam traps, among other uses.

  There are two classes of surface pyrometers: low temperature — up to 250°F; and high temperature — up to 600°F to 700°F.

  Noncontact surface pyrometers measure infrared radiation from a surface in terms of heat. Optical pyrometers, applicable only to high temperature measurements (over 1500°F) measure the temperature of the surfaces of bodies that incandesce.

Psychrometer: The psychrometer measures relative humidity based on the relationship of dry-bulb temperature to wet-bulb temperature. Relative humidity is an especially important consideration in auditing HVAC systems and drying operations. Recording psychrometers are available.

Suction Pyrometer: The suction pyrometer, especially applicable to the measurement of high gas temperature, shields the thermocouple from wall radiation. By drawing gases over the thermocouple at high velocities, the suction pyrometer achieves good convective heat transfer. This makes it possible to approach measurement of actual gas temperature, rather than a temperature somewhere between the temperature of the gas and the walls.

- Electrical System Measurements

Ammeter: The ammeter makes a direct measurement of electrical current. There are both indicating ammeters and recording ammeters. The recording type permits measurement of current variations in a conductor over a period of time and records results on paper.

Voltmeter: A voltmeter is used to measure the difference in potential between two points in a circuit. In series with the instrument's probes are a fixed resistance (which determines the scale of the reading) and a galvanometer. The current passing through the fixed resistance is proportional to the line voltage. Thus, the galvanometer deflects in proportion to line voltage.

Wattmeter: Although wattage can be calculated from current and voltage readings, the wattmeter makes a direct reading of wattage.

Power Factor Meter: The power factor meter, primarily a three-phase instrument, is useful for determining sources of poor power factor within a building's energy use system.

Footcandle Meter: The footcandle meter measures illumination levels. A barrier layer of photosensitive cells produces current that deflects a galvanometer. Unlike light meters used in photography, the footcandle meter is cosine and color corrected.

- Combustion System Measurements

Combustion Tester: The combustion tester determines the concentration of combustion products (typically CO_2 and CO) in stack gas and also tests for O_2 to assure proper excess levels.

The basic combustion test, the Orsat apparatus, takes a measured volume of stack gas and makes successive volume measurements after the gas has been in contact with selective absorbing solutions. The Orsat apparatus also determines the volume of each constituent by measuring the volume reduction after each absorption test. The Orsat apparatus, however, is a very complicated analytical tool, requiring much set-up and a high degree of operator skill and practice.

As an alternative to the Orsat apparatus, there are portable absorbing instruments that determine stack gas constituents on an individual basis.

Boiler Test Kit: A typical boiler test kit contains three gas analyzers (CO, CO_2, O_2) and an inclined manometer.

Gas Analyzers: The Fyrite gas analyzer, although more limited and less accurate than the Orsat apparatus, is simple, easy to use, and comparatively inexpensive. Fyrite gas analyzers are particularly suited for use in energy audits, despite lower accuracy. When Fyrite analyzers are used, three readings should be made and results averaged.

Draft Gauge: The draft gauge (either the pocket type or the inclined manometer) is used to measure pressure.

Smoke Tester: The smoke tester measures the completeness of combustion. (Smoke is unburned carbon, which wastes fuel, causes pollution, and fouls the surface of heat exchangers.) In use, the smoke tester's probe draws a volume of flue gas through filter paper. The smoke spot thus produced is then visually compared with a standard scale.

Combustion Analyzer: The electronic combustion analyzer permits fast, precise adjustments for selective readings, and uses a digital display for results. Its probe arrangement allows measurements to be made through a single stack or breaching hole.

- HVAC System Performance: Air Velocity Measurements

Smoke Pellets: The range of usefulness of smoke pellets is limited, but they are inexpensive and can provide acceptably accurate velocity measurements when used by experienced personnel.

Deflecting Vane Anemometer: This is an acceptably accurate measuring device that indicates air movement. The device costs approximately $50.

Revolving Vane Anemometer: This instrument also indicates air movement with acceptable accuracy. However, it is more expensive and more easily damaged than the deflecting vane anemometer.

Pitot Tube: This standard measuring instrument gives good accuracy. Available in lengths ranging from 12" (approximately $20) to 48" ($35), the pitot tube must be used with a manometer (approximately $20 to $60).

Impact Tube: This device, which is convenient to use and sufficiently accurate for most auditing, is usually packaged in an airflow meter kit that includes several jets for testing airflow in ducts, grilles, open areas, and so forth. Typical kit prices range from $150 to $300.

Heated Thermocouple: This instrument is very sensitive and accurate, but its cost (approximately $500) makes it impractical for most auditing applications.

Hot-Wire Anemometer: This airflow measuring device is too expensive and complicated for any auditing applications except the most critical monitoring processes.

- HVAC System Performance: Temperature Measurement

Glass Thermometers: Available in various ranges, glass thermometers are accurate, convenient, inexpensive, and fragile.

Resistance Thermometers: Very useful for air conditioning system testing, resistance thermometers are accurate, reliable, and easy to use. Prices begin at approximately $150.

Thermocouples: Although similar to the resistance thermometer, chrome alum or iron thermocouples do not require battery power sources. They are acceptably accurate and comparatively inexpensive (from $50 up).

Pressure Bulb Thermometers: These accurate and reasonably priced thermometers (approximately $40 and up) are most suitable for permanent installation.

Optical Pyrometers: Limited in usefulness to furnace settings, these instruments cost from $300 up.

Radiation Pyrometers: These instruments are expensive (approximately $500 up) and limited in use.

Indicating Crayons: Although limited in use and not suitable for most air conditioning audit applications, crayons are inexpensive ($2) and may be used in some auditing processes.

Thermographs: Reasonably accurate and inexpensive ($30 to $60), thermographs record room or space temperature and produce a chart that records variations over periods of 12 to 168 hours.

- HVAC System Performance: Pressure Measurement

Micromanometer: Although not usually a portable instrument, the micromanometer is useful for measuring pressure differentials, and costs from $30 up.

Draft Gauges: Frequently designed to be portable, draft gauges can measure pressure directly or measure pressure differentials. A draft gauge costs from $30 up.

Manometers: Used for direct pressure measurements and with pitot tubes for airflow measurement, manometers are frequently portable and cost approximately $30.

Swing Vane Gauges: Usually used to measure airflow, these gauges are portable and cost approximately $30.

Bourdon Tube Gauges: Very useful for measuring all types of system fluid pressure over 5 psi, these gauges vary in cost — the least expensive starting at approximately $10.

- HVAC System Performance: Humidity Measurement

Psychrometers: These are essentially wet and dry-bulb thermometers, which are inexpensive ($10 to $30) and convenient.

Electrical Conductivity: Instruments using this measurement process are frequently portable and compact, but comparatively expensive (from $200 up).

INFRARED THERMOGRAPHY

Infrared energy is an invisible section of the electromagnetic spectrum, the wavelength of which is slightly longer than that of visible light. (See Table 2.) Recent technological advances have produced portable equipment capable of making remote measurements of infrared energy radiating from surfaces. The hotter a given surface, the more infrared radiation the surface emits. Differences in infrared radiation cause color variations on the screens of infrared scanners. These color variations are interpreted to determine where a building or energy system is losing heat.

TABLE 2. THE ELECTROMAGNETIC SPECTRUM.

Gamma Rays	X-Rays	UV	Visible	Infrared	Microwave	Radio Wave
10^{-6}	10^{-5}	10^{-2}	0.4	0.75	10^{3}	10^{6}
high energy radiation, short wavelength						low energy radiation, long wavelength

Wavelength is expressed in micrometers (μm).

The infrared detector absorbs infrared energy and converts it into electrical current. This current, in the thermal infrared scanner, develops an image of infrared radiation differences on photographic film. Photo-type infrared scanners use current to produce an image on a cathode-ray tube, thus permitting analyses that track processes dynamically and in real time.

Typically, the lightest colors on the display represent the warmest temperatures, while the darkest colors represent coolest temperatures. Sensitivity of currently available equipment is in the range of -30°C to over 2000°C, with an accuracy of less than 0.1°C.

For most sophisticated auditing purposes, hand-held infrared scanners are sufficient. However, there are companies that provide aerial infrared scanning services that, in addition to showing heat losses through the building envelope, can also reveal underground steam pipe leaks, hot gas discharges, leaks, and other losses difficult or impossible for the auditor to detect from the ground.

The variety of infrared scanning devices is wide, both in configuration and cost. Capabilities and instructions for use of particular units are provided by the manufacturers. Typical prices range from $400 to $50,000.

ENERGY SAVING POTENTIAL

The following are a few energy management and conservation opportunities. While this list is only a beginning, it should encourage the student to consider the relationship of auditing to energy conservation.

CONSERVATION OPPORTUNITIES WHILE HEATING BUILDINGS

The amount of energy or fuel required to heat a building is dependent upon the level of temperature and relative humidity indoors; the amount of ventilation and infiltration air that must be heated; the severity and duration of the outdoor temperature below indoor room conditions; the thermal properties of the building envelope; and the efficiency of the distribution system, burners, boilers, and furnaces.

Directive 1: Maintain lower indoor temperatures during the heating season.

- Lower indoor temperatures reduce the heating load due to ventilation and infiltration – as well as heat loss by conduction through the building envelope.
- Lower the thermostat setting to 68°F or less during occupied hours.
- Lower the thermostat setting to 58°F or less at night, on weekends, and during all other unoccupied periods.
- After reducing the heating loads, adjust the distribution system, boiler, and burner accordingly to further reduce fuel consumption.
- See Example A.

EXAMPLE A: SAVINGS BY NIGHT SETBACK.

A. OPERATIONAL CHANGE: Thermostats lowered from 68° to 58°F at night, weekends, and holidays.

B. ASSUMPTIONS:

Office building – Chicago, Illinois (6,500 degree days.)
Floor area – 50,000 square feet.
Conditions before operational change – Building occupied 40 hours per week; outside air supplied only during occupied periods; fuel consumption, 64,000 gallons of oil per year at $1/gallon.

Example A. Continued.

C. SAVINGS:

Energy – 8,200 gal/yr; a savings of 12.8%.
Dollars – $8,200/yr.

D. IMPLEMENTATION COST: None.

Directive 2: Shut OFF outside air during all unoccupied periods.

- Close outside air dampers or shut OFF outside air fan during unoccupied hours of the heating season, including noon-day periods when buildings may be lightly occupied and periods when areas such as auditoriums, cafeterias, gymnasiums, dormitories, and conference rooms are unoccupied.

- Reduce or shut OFF outdoor air entirely in retail stores during periods of the day when occupancy is considerably less than normal.

- In religious buildings, shut OFF outdoor air for all days during the week, as well as nights, when the buildings are unoccupied.

- See Example B.

EXAMPLE B: SAVINGS BY SHUTTING OFF VENTILATION.

A. OPERATIONAL CHANGE: Shut OFF outside air at night and other unoccupied periods by closing outside air dampers of air-handling unit.

Example B. Continued.

B. ASSUMPTIONS:

Office building – Minneapolis, Minnesota (8,400 degree days).
Floor area – 300,000 square feet.
Conditions before operational change – Unoccupied 128 hours per week; outdoor air supplied 24 hours per day at 30 cubic feet per minute (cfm) per person; fuel consumption = 250,000 gallons of oil per year at $1/gallon.

C. SAVINGS:

Energy – 68,100 gal/yr; a savings of 32.5%.
Dollars – $68,100/yr.

D. IMPLEMENTATION COST: None.

Directive 3: Reduce the quantity of outdoor air for ventilation during occupied hours.

- Reduce the amount of ventilation air during occupied hours by setting outside air dampers and controls. Generally, only 5 cfm per person is necessary to maintain proper air quality, but smoking in many areas may raise the average requirements to about 8 cfm person.

- See Example C.

EXAMPLE C: SAVINGS BY REDUCING VENTILATION RATE.

A. OPERATIONAL CHANGE: Adjust dampers to reduce outdoor air from 22 cfm per person to 8 cfm per person during occupied hours.

Example C. Continued.

B. ASSUMPTIONS:

Office building – Minneapolis, Minnesota (8,400 degree days).
Floor area – 350,000 square feet.
Conditions before operational change – Occupied 40 hours per week; outdoor air = 30 cfm per person; 2,000 occupants = 60,000 cfm; fuel consumption = 450,000 gallons of oil per year at $1/gallon.

C. SAVINGS:

Energy – 137,104 gal/yr; a savings of 30%.
Dollars – $137,104/yr.

D. IMPLEMENTATION COST: None.

Directive 4: Reduce the rate of infiltration.

- Air infiltrates through cracks around doors and windows, through construction joints, and through doors that are frequently opened. Infiltration occurs whether the building is occupied or not. When exhaust fans are operating and outdoor air ventilation is insufficient to provide make-up air, infiltration rates increase.
- Reduce air leakage by sealing and caulking leaks around windows and doors.
- Seal construction joints.
- Reduce exhaust air volume and operating hours of exhaust systems.
- See Example D.

EXAMPLE D: SAVINGS DUE TO CAULKING

A. OPERATIONAL CHANGE: Caulk windows to reduce infiltration rate from one air change per hour to one-half air change per hour.

B. ASSUMPTIONS:

School – Fargo, North Dakota (9,000 degree days).
Floor area – 300,000 square feet.
Conditions before operational change – Occupied 36 hours per week; average indoor temperature during unoccupied periods = 60°F; existing double windows (26,000 square feet) = 1,000 windows; present fuel consumption = 225,000 gallons per year at $1/gallon.

C. SAVINGS:

Energy – 33,300 gal/yr; a savings of 14.8%.
Dollars – $33,300/yr.

D. IMPLEMENTATION COST: $10,000 (for caulking material and labor).

Directive 5: Reduce fan horsepower.

- The quantity of air (in cfm) circulated for heating often can be reduced in response to reduced heating loads, or upon an analysis indicating that the current cfm circulated is not required. Air quantities, set for cooling loads, may often be reduced during the heating season when the same system is used for both heating and cooling. Reducing the air quantity for systems operating against high static pressures, with motors 25 horsepower or larger, can result in significant savings during both the heating and cooling season.

- See Example E.

EXAMPLE E: ENERGY SAVINGS BY REDUCING AIRFLOW.

A. OPERATIONAL CHANGE: Reduce supply air quantity by 20% by reducing fan speed 6%. Fan speed is reduced by changing the driver pulley.

B. ASSUMPTIONS:

Retail store – New York, New York.
Floor area – 100,000 square feet.
Conditions before operational change – Air quantity = 1-1/2 cfm/sq ft; 1-1/2 cfm x 100,000 sq ft = 150,000 cfm at static pressure. Fans operate for 2,500 hours per year. Energy used 360,000 kWh/yr at 5¢/kWh.

C. SAVINGS:

Energy – 118,000 kWh/yr; a savings of 33%.
Dollars – $5,940/yr.

D. IMPLEMENTATION COST: Less than $500 (for pulley change and labor).

Directive 6: Improve combustion and boiler efficiency.

- The efficiency of the boiler/burner unit or furnace decreases rapidly when combustion is improper, when the combustion surfaces accumulate soot and scale, or when excess combustion air increases the stack temperature. Any percentage increase in seasonal boiler/burner efficiency directly reduces fuel consumption in the same proportion.
- Test the combustion efficiency with proper instruments and adjust the firing rate and combustion air rate accordingly.
- Adjust the automatic damper to control the draft in accordance with the firing rate.
- Remove scale and soot from the boiler.
- See Example F.

EXAMPLE F: ENERGY SAVINGS BY IMPROVING COMBUSTION EFFICIENCY.

A. OPERATIONAL CHANGE: Descale boiler surfaces. Remove soot. Adjust combustion efficiency to improve boiler-burner efficiency by 10%.

B. ASSUMPTIONS:

Retail store – New York, New York (4,800 degree days).
Floor area – 100,000 square feet.
Conditions before operational change – Fuel consumption = 100,000 gallons of oil per year at $1/gallon; occuped 72 hours per week.

C. SAVINGS:

Energy – 10,000 gal/yr; a savings of 10%.
Dollars – $10,000/yr.

D. IMPLEMENTATION COSTS: $1,500/yr (to service burner and boiler at four-month intervals during the heating season).

COOLING

The amount of energy required to cool a building is dependent upon the level of temperature and relative humidity indoors; the amount of ventilation air and infiltration air that must be cooled and dehumidified; the severity and duration of the outdoor temperature and humidity above indoor room conditions; the thermal properties of the building envelope; the heat gain through walls, roof, and windows due to solar radiation; and the magnitude and duration of the internal heat gain due to people and to equipment that emits heat and/or moisture.

Directive 7: Operate the system at appropriate hours.

- Shut OFF all refrigeration equipment and auxiliaries, including fans, pumps, cooling towers, and condensers, during all unoccupied hours — at night, on holidays, and weekends.
- Delay the operation of the refrigeration system for one or two hours in the morning and shut OFF prior to closing time, except in the most severe hot spells.
- See Example G.

EXAMPLE G: SAVINGS DUE TO REDUCING THE NUMBER OF HOURS OF OPERATION OF THE COOLING SYSTEM DURING OCCUPIED HOURS.

A. OPERATIONAL CHANGE: Entire cooling system operated two hours less per day for six days per week.

B. ASSUMPTIONS:

Retail department store — New York, New York.
Floor area — 250,000 square feet.
Conditions before operational change — Cooling system operated 84 hours per week; electric rate = 5¢/kWh.

C. SAVINGS:

Energy — 234,800 kWh/yr; a savings of 14%.
Dollars — $11,700/yr.

D. IMPLEMENTATION COST: None.

Directive 8: Reduce the quantity of outdoor air ventilation.

- Measures to reduce outside air ventilation (and infiltration) to conserve heating energy will also result in decreased summer cooling loads. Where infiltration exceeds one-half of an air change per hour for buildings in humid climates, measures to reduce infiltration will provide major energy savings for cooling, as well as for heating.

- During occupied hours, reduce the amount of air for ventilation as in the measure described in Directive 2.

- See Example H.

EXAMPLE H: SAVINGS BY REDUCING THE AMOUNT OF OUTDOOR AIR FOR VENTILATION.

A. OPERATIONAL CHANGE: Adjust dampers to reduce outdoor air from 30 cfm to 8 cfm per person during occupied hours.

B. ASSUMPTIONS:

Office building – Miami, Florida.
Floor area – 100,000 square feet.
Conditions before operational change – Occupied 40 hours per week; outdoor ventilation air at 30 cfm per person x 667 occupants = 20,000 cfm; electric costs = 5¢/kWh. Annual energy consumption for chiller = 715,000 kWh/yr at 5¢/kWh.

C. SAVINGS:

Energy – 63,000 kWh/yr; a savings of 8%.
Dollars – $3,150/yr.

D. IMPLEMENTATION COST: None.

Directive 9: Use outdoor air for free cooling.

- For the many periods during the year when dry-bulb temperature is below the setting for room conditions, the use of outdoor air for cooling reduces the hours of operation of the refrigeration system.
- Using outdoor air at night to reduce the late afternoon sunloads that are stored in the building mass and precooling the building will result in fewer hours of compressor operation on the following day.
- Enthalpy control may be even more effective in saving energy in locations where there are fewer than 8,000 wet-bulb degree hours.
- On cool days, open the damper to circulate 100% outdoor air for sensible cooling. It may be necessary to open the windows slightly to relieve pressure.
- If equipped with an enthalpy controller, set it to permit full outdoor air supply when the total heat content of the outdoor air is below room conditions.
- See Example I.

EXAMPLE I: SAVINGS BY USING OUTDOOR AIR DURING OCCUPIED PERIOD IN AN ECONOMIZER CYCLE.

A. OPERATIONAL CHANGE: Operate an economizer cycle for 690 hours per year by opening the outdoor air damper, closing the return air damper, and opening a few windows for pressure relief.

Example I. Continued.

B. ASSUMPTIONS:

Office building – Denver, Colorado.
Floor area – 50,000 square feet.
Conditions before operational change: Occupied 40 hours per week; annual energy consumption for chiller: 245,000 kWh/yr at 5¢/kWh; refrigeration cycle OFF at night.

C. SAVINGS:

Energy – 85,000 kWh/yr; a savings of 34.7%.
Dollars – $4,250/yr.

D. IMPLEMENTATION COST: None.

Directive 10: Permit higher indoor temperatures and relative humidity during occupied hours.

- By allowing higher temperature and humidity conditions in the summer, the cooling load is reduced and chillers or compressors will operate fewer hours and consume less energy per hour of operation. Higher room temperatures will also permit a reduction in supply air quantity with a savings in motor horsepower.
- See Example J.

EXAMPLE J: SAVINGS BY RAISING INDOOR TEMPERATURE HUMIDITY LEVELS AND CHILLED WATER TEMPERATURES.

A. OPERATIONAL CHANGE: During the cooling season, raise indoor temperatures from 72°F to 78°F and relative humidity from 50% to 60%. Raise chilled water temperatures from 42°F to 46°F.

B. ASSUMPTIONS:

Office building – Miami, Florida.
Floor area – 100,000 square feet; number of stories – 10.
Conditions before operational change – Building occupied 40 hours per week; annual energy consumption for chiller – 715,000 kWh at 5¢/kWh.

C. SAVINGS:

Energy – 115,000 kWh/yr; a savings of 16%.
Dollars – $5,750/yr.

D. IMPLEMENTATION COSTS: None, if done manually.

Directive 11: Reduce the solar heat gain through windows.

- The solar heat gain through windows can be a large percentage of the cooling load in office buildings, schools, and in small stores where show windows are in direct sunlight.
- The greatest amount of solar radiation in the cooling season strikes the west and east glass. The next greatest amount of solar radiation strikes the southern facade.
- Reduce the solar heat through windows by adjusting existing awnings, blinds, or drapes on each window when they are in direct sunlight.

- Add relfective solar film to all windows in direct sunlight.

- See Example K.

EXAMPLE K: SAVINGS BY REDUCING SOLAR HEAT GAIN.

A. OPERATIONAL CHANGE: Reflective solar film* should be added to east, west, and south windows to reduce shade coefficient from 0.9 to 0.15. Air and chilled systems operation should be reduced accordingly.

B. ASSUMPTIONS.

Office building – Miami, Florida.
Floor area – 100,000 square feet; number of stories – 10.
Conditions before operational change – Cooling system in operation 40 hours per week; window area on west, south, and east facade – 10,000 sq ft existing windows – clear, single glazed. Annual energy consumption for cooling = 1,100,000 kWh at 5¢/kWh.

C. SAVINGS:

Energy – 170,000 kWh/yr; a savings of 15%.
Dollars – $8,500/yr.

D. IMPLEMENTATION COST: At installation cost of $2.25 per square foot = $22.500.

*The film may require replacement after 8 to 10 years.

Directive 12· Reduce supply and return airflow and chilled water quantities.

- Reducing the cooling loads and analyzing the operation of the existing air conditioning system make possible many opportunities to reduce fluid flow.

- While dampering (in the case of air ducts) and valving (in the case of water piping) will reduce flow rate and energy input to motors, greater savings can be gained by reducing motor speed (and/or for piping system, by changing the impellers). For systems with motors drawing 25 brake horsepower (bhp) or more, the yearly savings can be very significant. CAUTION: Do not neglect the smaller motors and systems; their aggregate energy draw may be very high. Follow references in Directives 6 and 7 for fan and motor modifications during periods when the cooling system is in operation.

Directive 13: Clean and descale condenser tubes.

- The efficiency of chillers and refrigeration condensers decreases markedly as scale builds up in the tubes. Check condenser temperatures on a regular basis and descale tubes at least once per year.

- See Example L.

EXAMPLE L: SAVINGS BY CONDENSER MAINTENANCE.

A. OPERATIONAL CHANGE: Descale condenser tubes to reduce fouling factor to 0.00005 or less.

B. ASSUMPTIONS:

Retail department store – Dallas, Texas.
Floor area – 100,000 square feet.

Example L. Continued.

Conditions before operational change – Building occupied 72 hours per week; average fouling factor = 0.001; annual energy consumption for chillers = 650,000 kWh/yr at 5¢/kWh.

C. SAVINGS:

Energy – 116,000 kWh/yr; a savings of 18%.
Dollars – $5,800/yr.

D. IMPLEMENTATION COST: $2,000/yr (to maintain the condensers and all air conditioning equipment).

Directive 14: Operate at higher chilled water and suction temperatures to increase the efficiency of the refrigeration chillers.

- There are extensive periods of time (in some cases, the entire year) during which the chilled water temperature can be raised by 4° or 6° or more. Accordingly, the refrigeration compressor or chiller can operate at higher suction temperatures. An increase of 1° in the suction temperature of the chiller (or compressor in direct expansion systems) results in a reduction of 1-1/2 to 2% in the power requirement for the refrigeration unit. The savings in operating costs by increasing chilled water or suction temperatures for systems of 15 horsepower (hp) and more are significant.

- Raise the chilled water temperature from 2 to 8 degrees higher when cooling load permits.

- Raise the chilled water temperature in buildings for those portions of the day when cooling loads are likely to be lower (i.e., during slack business hours in retail stores;

noon hours when office buildings are partially vacated; morning, pre-occupancy periods after a night shutdown).

- See Example M.

EXAMPLE M: ENERGY SAVINGS BY RAISING CHILLED WATER TEMPERATURE.

A. OPERATIONAL CHANGE: Raise chilled water temperature from 42° to 48°F for all normal operations.

B. ASSUMPTIONS:

Retail department store – Los Angeles, California.
Floor area – 50,000 square feet.
Conditions before operational change – Building occupied 72 hours per week; cooling system OFF at night; present energy consumption for refrigeration = 320,000 kWh/yr at 5¢kWh.

C. SAVINGS:

Energy – 32,000 kWh/yr; a savings of 10%.
Dollars – $1,600/yr.

D. IMPLEMENTATION COST: None, if done manually; nominal cost for controller and sensor (for automatic operation).

Directive 15: Reduce the condensing temperature of commercial refrigeration units to improve operating efficiency.

- In general, air-cooled condensing units serve a large number of supermarket refrigeration cases. These units are often crowded into storage areas where they are partially blocked, mounted outdoors in direct sunlight, or mounted and neglected on the roof or another remote location.

- See Example N.

EXAMPLE N: ENERGY SAVINGS BY REDUCING CONDENSING TEMPERATURE.

A. OPERATIONAL CHANGE: Condenser coils for refrigeration cleaned to reduce average condensing temperature from 115° to 95°F.

B. ASSUMPTIONS:

Supermarket – New York, New York.
Floor area – 25,000 square feet.
Conditions before operational change – 120 hp installed capacity; refrigeration units operate an average of 12 hours per day or 4,380 hours per year.
Annual energy consumption for refrigeration = 420,000 kWh/yr at 5.5¢/kWh.

C. SAVINGS:

Energy – 84,000 kWh/yr; a savings of 20%.
Dollars – $4,620/yr.

D. IMPLEMENTATION COST: Negligible.

LIGHTING

Modification to the operation of the lighting system and to the system itself provides the greatest opportunity to reduce energy consumption. Simply turning OFF unnecessary lights, day and night, and making greater use of available daylight for illumination, saves energy for both lighting and air conditioning with no added costs. Better cleaning and maintenance practices increase the efficiency of the lighting system and provide the opportunity for lamp replacement (by lamps of lower wattage) or removal, or the switching OFF of lights – with little or no reduction in illumination levels.

Directive 16: Utilize daylight to reduce the lighting load.

- Windows, properly exploited, can provide a sizeable part of the illumination required in small stores and office buildings during a large portion of the building's occupied hours.

- Open drapes and blinds during the day to take advantage of daylight at the perimeters of the building, while controlling glare and excessive solar radiation. It should be recognized that excess daylight may cause materials to fade and change color.

- Switch OFF the lights that are not needed when daylight can supply necessary illumination.

- See Example O.

EXAMPLE O: ENERGY SAVINGS BY REDUCING LIGHTING LOAD.

A. OPERATIONAL CHANGE: Perimeter lights turned OFF approximately 50% of occupied hours.

B. ASSUMPTIONS:

Office building – New York, New York.
Floor area – 100,000 square feet; number of stories – 10.
Glass area – 33% of net wall area.

Example O. Continued.

Available daylight – 50% of occupied hours.
Switching arrangement – Separate switches for perimeter row of lights.
Electricity used for lighting – 935,000 kWh at 5.5¢/kWh.

C. SAVINGS:

Energy – 159,000 kWh/yr; a savings of 17%.
Dollars – $8,745/yr.

D. IMPLEMENTATION COST: None.

Additional savings in energy for cooling and refrigeration equipment will also result from reduced interior heat gain.

Directive 17: Turn OFF lights when entire building or portions are unoccupied.

- A large percentage of energy used for lighting is wasted when all lights are burning and only a small portion of the building is in use.
- Turn OFF lights at night.
- Turn OFF lights in auditoriums, conference rooms, cafeterias, computer rooms, and other areas when not used during the day.
- Schedule cleaning hours during daylight. If this is not possible, illuminate only that portion of the building that is being cleaned at any one time.
- See Example P.

EXAMPLE P: ENERGY SAVED BY TURNING OFF LIGHTS.

A. OPERATIONAL CHANGE: Lighting turned ON at 8:00 a.m. and OFF at 5:00 p.m. for five days per week. Minimal night lighting during unoccupied hours.

B. ASSUMPTIONS:

Office building – New York, New York.
Floor area – 100,000 square feet.
Conditions before operational change – Building occupied 40 hours per week. Lighting turned ON at 7:00 a.m. and OFF at 7:00 p.m. for five days per week. Connected lighting load of 4 watts per square foot = 400,000 kWh x 5.5¢/kWh.

C. SAVINGS:

Energy – 300,000 kWh/yr; a savings of 25%.
Dollars – $16,500/yr.

D. IMPLEMENTATION COST: None.

Directive 18: Reduce illumination levels to reduce lighting load.

- Lighting levels are frequently higher than necessary for a given task and can be reduced in many areas of a building during the day to suit the task being performed. The level of illumination necessary over filing cabinets, dead corners, storage areas, and some clerical areas need not be as high as those levels for accounting areas, drafting tables, or detail work stations occupied for many hours per day. Uniform lighting in large areas can be unnecessary and wasteful; different tasks done in an area may require different light levels. Reduce lighting levels when possible.

- Maintain existing lighting system to improve the footcandles/watt output.

- Analyze the tasks to be performed and reduce the levels where the tasks are not so critical by:
    a. Replacing existing lamps with lower wattage, lower output lamps.
    b. Removing some lamps and ballasts from fixtures.
- See Example Q.

EXAMPLE Q: SAVING ENERGY BY REDUCING LIGHT LEVEL THROUGH REMOVING LAMPS AND BALLASTS.

A. OPERATIONAL CHANGE: Remove two of the four lamps from half of the overhead 2' x 4' fluorescent fixtures and disconnect the associated ballasts.

B. ASSUMPTIONS:

Retail department store – Los Angeles, California.
Floor area – 100,000 square feet.
Conditions before operational change – Lights on for 72 hours per week; lighting levels average 80 footcandles; electric use = 1,400,000 kWh/yr at 5¢/kWh.

C. SAVINGS:

Energy – 375,000 kWh/yr; a savings of 28%.
Dollars – $18,750/yr.

D. IMPLEMENTATION COST: $4,000 (to remove lamps and disconnect ballasts). New lighting levels average 65 footcandles. Note that the level of illumination decreased only 16%.

Directive 19: Reduce the level of illumination in parking lots to reduce electric load.

- Parking lots require an average of only one footcandle of even illumination. Overlighting, inefficient light sources, and unnecessarily prolonged periods of operation account for excessive energy usage.
- Reduce the level of lighting if over one footcandle, while maintaining reasonable uniformity of illumination.
  - a. Replace lamps with more efficient light sources.
  - b. Reduce wattage of lamps or remove unnecessary ones.
- See Example R.

EXAMPLE R: SAVING ENERGY BY REDUCING LIGHTING LEVEL IN PARKING LOT.

A. OPERATIONAL CHANGE: Reduce the wattage of the lamps in a parking lot to reduce lighting levels to an average of one footcandle.

B. ASSUMPTIONS:

Retail store 2,500-car parking lot — Chicago, Illinois.
Conditions before operational change — Lights operated 4 hours per day x 315 days per year = 1,260 hours per year to maintain an average of 2 footcandles; electric usage = 256,000 kWh at 4.5¢/kWh.

C. SAVINGS:

Energy — 128,000 kWh/yr; a savings of 50%.
Dollars — $5,760/yr.

D. IMPLEMENTATION COST: None, when lamps are changed at normal relamping periods.

DOMESTIC HOT WATER

Opportunities to conserve energy used to heat water at minimal cost include lowering the temperature of hot water at the faucets and reducing the volume of water used.

In general, office buildings use two to three gallons of hot water per capita per day. Residences use about 20 gallons per capita per day. Religious buildings and stores use less. Hospitals, laundries, cafeterias, and restaurant kitchens use considerably more.

Heat loss from storage tanks and circulating pipes is proportional to the temperature difference between the water and ambient air. Therefore, reducing the maintained temperature of hot water not only reduces the amount of energy required to heat each gallon of water used, but also reduces the heat loss from the tank and piping system.

In buildings that have kitchens requiring very hot water for dishwashing, boost the temperature at the faucet, rather than maintaining a high-temperature hot water system for the entire building. For instance:

- Reduce the temperature of hot water at faucets to 90°F.
- Reduce the consumption of hot water in all buildings by flow restrictors in the piping, self-closing faucets, or flow restrictor taps.

Directive 20: Reduce the quantity and temperature of domestic hot water.

- See Example S.

EXAMPLE S: SAVINGS BY REDUCING TEMPERATURE AND QUANTITY OF HOT WATER.

A. OPERATIONAL CHANGE: Install 1/2 gpm spray nozzles on lavatory faucets and reduce temperature from 135° to 90°F.

B. ASSUMPTIONS:

Office building – New York, New York.
Occupancy – 3,500 people.
Conditions before operational change – Hot water usage: 2 gallons per day per capita – 135°F delivery temperature; total consumption = 7,000 gallons per day; oil consumption for hot water = 12,000 gallons per year at $1/gallon.

C. SAVINGS:

Energy – 6,240 gal/yr; a savings of 52%.
Dollars – $6,240/yr.

D. IMPLEMENTATION COST: $2,500 (for spray valves).

CALCULATING SIMPLE PAYBACK

There are several accepted approaches to calculating the period of time that may be required for the energy cost savings of the energy conservation measures (ECMs) to equal the initial investment. The variations generally relate to interest rates, availability of capital, projected fuel prices, and so forth.

For purposes of the energy audit, however, calculating simple payback is sufficient. It is the simplest to calculate and is generally quite effective in measuring the relative need for ECMs. (Simple payback is the specific method of calculation for the energy audit required by NECPA.)

To determine the simple payback, divide the estimated implementation cost of the ECM by the estimated annual energy savings. The result is the number of years required to pay off the initial capital investment.

$$\text{Simple Payback (years)} = \frac{\text{Initial Cost of ECM in \$}}{\text{Annual Energy Savings in \$}}$$

Equation 1

Generally, authorities recommend not proceeding with items that require more than a 7-to-10-year payback. This practice varies according to local needs, financial situation, and political climate. The projects selected first are almost always going to have the fastest and most far-reaching results.

LIFE-CYCLE COSTING

Simple payback calculation and ranking is an accurate way to compare energy conservation options, but is intended only for comparison. Actual dollar savings to implement a conservation option must include energy price escalation on a life-cycle basis.

Life-cycle costing is the dollar savings accrued by an energy saving option over its life.

Suppose an energy saving option with a seven-year life cycle saved $100 a year in energy costs at current prices. If energy did not increase in cost, then the energy option would have saved $700 over its seven-year life. However, prices of energy are escalating at approximately 20% per year. As a result, an option that saves $100 this year will save much more in the future. Table 3 is used to find the appropriate escalation factor at selected escalation rates.

TABLE 3. ENERGY PRICE ESCALATION.

	Escalation Factor			
Escalation Rate	5 years	7 years	10 years	15 years
10%	6.72	10.44	17.53	34.95
15%	7.75	12.73	23.34	54.72
20%	8.93	15.50	31.15	86.44

For example, the escalation factor for an option with a seven-year life expectancy and at a 20% escalation rate would be 15.50. To determine life-cycle costing, multiply the escalation factor times the first year's savings. If an item saves $100 the first year and has a seven-year life expectancy, then:

$100 x 15.50 = $1,500 saved over the life of the item.

Equation 2

In addition to material cost, equipment cost, labor cost, design cost, project supervision cost, and energy price escalation, other factors should be considered in determining the investment return in an energy conservation project for a building. These factors include recurring costs in connection with the operation, preventive and corrective maintenance, and inventory management of the energy conservation measures. In order to give a building owner a true picture of the energy cost savings over the lifetime of the measure, all relevant factors must be considered.

EXERCISES

1. Refer to the Energy Saving Potential section of this module's Subject Matter, and calculate simple payback for the following:
   a. Example D (Directive 4)
   b. Example E (Directive 5)
   c. Example K (Directive 11)
   d. Example Q (Directive 18)
   e. Example S (Directive 20)
2. For the same examples, calculate life-cycle costing, assuming the following data:
   a. Example D, 5-year life expectancy, 10% energy escalation rate
   b. Example E, 15-year life expectancy, 15% energy escalation rate
   c. Example K, 7-year life expectancy, 20% energy escalation rate
   d. Example Q, 10-year life expectancy, 15% energy escalation rate
   e. Example S, 5-year life expectancy, 10% energy escalation rate

LABORATORY MATERIALS

Anemometer (deflecting vane or revolving vane)
Footcandle meter
Surface pyrometer
Stem thermometer
Electric thermometer
Manufacturers' brochures and instruction manuals on these instruments and as many other energy audit instruments as possible

LABORATORY PROCEDURES

The purpose of the laboratory section of this module is to familiarize the student with energy auditing instrumentation. Students will become familiar with the configuration and operation of as many of the instruments discussed in the module as possible, and make the following measurements, the results of which will be recorded on the Data Table.

1. Using the anemometer, measure the air speed in the following locations:
   a. HVAC register
   b. Outside windows or doors on four major walls
2. Measure the illumination level on a laboratory table with a footcandle meter.
3. Use a surface pyrometer to measure the temperature on the following surfaces:
   a. Inside surface of an exterior window
   b. Sunlit interior wall
   c. Shaded portion of the wall measured in Item b
4. Measure hot water temperature at the faucet, using a stem thermometer.
5. Measure hot water temperature at the faucet, using an electric thermometer. Compare reading with that obtained with stem thermometer.

DATA TABLE

DATA TABLE. USING MEASURING INSTRUMENTS.

	Readings
Anemometer	
Air Speed: HVAC register	
Wall 1	
Wall 2	
Wall 3	
Wall 4	
Footcandle Meter	
Footcandles on Laboratory Table	
Surface Pyrometer	
Temperature of: Window surface	
Sunlit wall	
Shaded wall	
Stem Thermometer	
Temperature of Hot water	
Electric Thermometer	
Temperature of Hot water	

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Guidelines for Saving Energy in Existing Buildings: Engineers, Architects, and Operators Manual, ECM 2. U.S. Department of Commerce, National Technical Information Service PB-249924.

Practical Energy Management in Health Care Institutions. Blue Cross of Greater Philadelphia, 1977.

Thumann, Albert. *Handbook of Energy Audits*. Atlanta: Fairmont Press, 1979.

Total Energy Management for Hospitals. Hyattsville, MD: Department of Health, Education and Welfare, Publication No. 78-613, 1978.

TEST

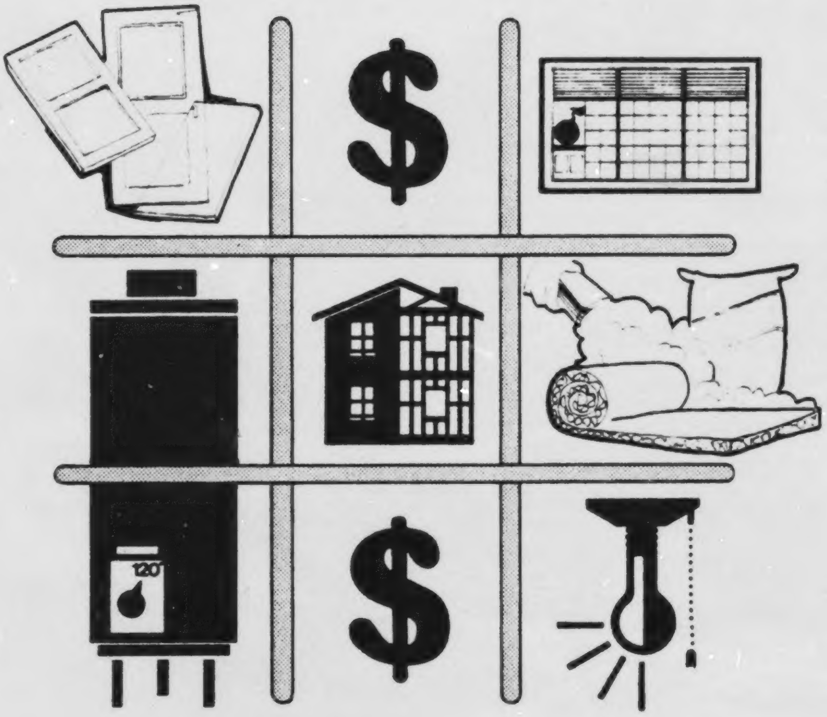
1. Caulking material and labor to reduce the rate of air infiltration in an institutional building cost $15,000. Heating oil consumption before implementation of the measure was 271,000 gallons per year. Energy consumption was reduced 17%. The cost of heating oil was $0.93/gallon. The simple payback period for this energy conservation measure is ...
   a. 1.1 year
   b. 2.1 years
   c. 0.35 year
   d. 0.53 year
2. Determine life-cycle costing for the conservation measure described in Question 1, assuming an energy cost escalation rate of 15% and a 5-year life expectancy for the measure. The amount saved over the life of the caulking is:
   a. $7,011.21
   b. $332,048.75
   c. $691,003.63
   d. $89,041.19
3. Psychrometers measure ...
   a. infrared radiation.
   b. illumination levels.
   c. stack gas constituents.
   d. relative humidity.
4. An impact tube is usually part of a kit which includes ...
   a. pitot tubes.
   b. draft gauges.
   c. airflow test jets.
   d. resistance thermometers.

5. Smoke tester results are analyzed ...
    a. chemically.
    b. electronically.
    c. volumetrically.
    d. visually.
6. Manometers make direct measurements of ...
    a. temperature.
    b. pressure.
    c. relative humidity.
    d. conductivity.
7. Infrared thermography is most useful in measuring energy loss through ...
    a. incomplete combustion.
    b. HVAC ductwork leakage.
    c. building envelope radiation.
    d. low power factor.

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY AUDITS



MODULE EA-03

ENERGY AUDIT PROCEDURES AND ANALYSES

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

"Energy Audit Process and Analysis" describes energy auditing as a complete process. This module shows the relationship between the elements of the energy audit and the auditor's interactive role in total energy management. Various types of audits are discussed, as well as information the auditor is required to compile.

PREREQUISITES

The student should have completed Module EA-02, "Elements of an Energy Audit."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List the major types of energy audits.
2. Calculate an annual energy index.
3. Collect data from equipment nameplates.
4. Calculate energy consumption for lighting and electric motors.
5. Discuss the procedure for ranking energy conservation measures.
6. Discuss the auditor's role in total energy management.

THE ENERGY AUDITING PROCESS

The energy audit is the foundation of any energy conservation program. It identifies all energy systems in a building or industrial plant (facilities) and measures energy use. An energy audit makes it possible to determine (1) the energy use pattern of each system, (2) how the systems affect each other, and (3) a starting point against which the success of an energy conservation program can be measured.

Energy is supplied to facilities through a utility distribution network on a metered basis; however, some fuels can be stored on-site on a periodic basis.

Typically, local utilities supply electricity, natural gas, and purchased steam on a metered basis. Water is a utility that is not a direct source of energy, but is indirectly associated with energy conservation since it is used in boilers and for cooling compressors. Hence, its use should be audited. Fuels that can be stored on the plant site include fuel oil, propane, coal, wood, or waste fuel.

An energy audit is similar to the monthly closing statement of an accounting system. One series of entries consists of amounts of energy consumed during the month in the form of electricity, gas, fuel oil, coal, etc. The second series lists where this energy is used — lighting, air conditioning, heating, and other sources.

In other words:

Energy In = Energy Out

Various energy sources are converted to common energy units of Btus, according to their known heating values. Total energy use for the facility can be computed on a monthly basis and summed up to provide annual energy consumption. Energy use for the plant can be expressed as an Energy Utilization Index (see Module EA-01) or an Annual Energy Index.

All Btus are not provided at the same cost. Electric energy has been generated, transported, and delivered in a clean, versatile form. This is reflected in its relatively high cost per Btu, which includes cost elements for fossil or nuclear energy, energy conversion losses, transportation losses, and others. Similar considerations apply to purchased steam. Therefore, an energy management program includes both the cost and the energy value of the various energy sources. Relatively expensive energy sources, such as electricity, are expressed as a percentage of the total energy consumed by the facility. Along with the Energy Utilization Index (EUI) or Annual Energy Index (AEI), this information permits an accurate analysis of the facility's energy use characteristics.

The energy auditing process must be accurate enough to quantify the energy and cost savings resulting from energy-conserving modifications. Even the most thorough audit, however, cannot identify and quantify all energy consumption; some energy and energy losses simply cannot be accounted for. Thus, in order to account for all "Energy Out," estimates may have to show some energy that is unaccounted for.

TYPES OF ENERGY AUDITS

There is a direct relationship between the amount of energy use data collected and the number of energy-conserving opportunities evaluated. The cost of performing an audit increases in proportion to the amount of data collected. Best results will always come from a thorough analysis of all energy systems in a facility and their purposes and interaction. However, time and budget limitations may require action to be taken only in the selected areas where a less thorough audit has indicated the greatest potential for energy conservation.

WALK-THROUGH AUDITS

The walk-through audit is a very limited energy audit, which is made by visually inspecting the facility and considering the most applicable energy conservation opportunities on the basis of a general knowledge about facilities of a particular type. This simple audit can identify operation and maintenance energy-saving opportunities and determine whether a more complete analysis should be performed at a later date.

MINI-AUDITS

These audits require tests and measurements that quantify energy consumption and calculate the economics of making energy-conserving modifications. The mini-audit should focus on the major energy sources and energy use systems and on the most likely conservation opportunities. The report from such an audit should urge that energy conservation practices requiring little or no investment be adopted immediately.

MAXI-AUDITS

To provide a complete energy profile of a facility, an energy audit must be performed on the basis of a thorough engineering analysis. The maxi-audit, usually with access to this information about the facility being audited, identifies all energy systems and their interrelationships. Such an analysis can, among other things, determine opportunities for recovering waste energy. The maxi-audit is a total analysis, including the use of building models and climatological data, which involves sophisticated instrumentation. Maxi-audits should be performed by a qualified engineer and/or energy technician.

COMPUTER SIMULATION MODELS

Various computer simulation models, which are available from utilities and other sources in some areas, are useful aids for the energy auditor. They provide a realistic estimate of the overall energy needs in a facility of a particular type when compared to guidelines or norms. These programs are frequently available to the auditor at little or no cost.

Some computer output reports give the potential scope for energy savings, but may not specifically identify the modifications that will effect those savings. Such computer programs, however, can be a reasonable first approach to the issue of energy conservation and are closely related to estimators of building energy consumption such as the AEI.

Energy conservation will be an on-going process for many years. Therefore, it is important to overcome the initial obstacles and begin an energy audit program. First, a base line should be developed to serve as a reference point for an energy conservation program. The program can then be continued with successive refinements.

PERFORMING THE ENERGY AUDIT

The auditor is responsible for collecting a variety of information concerning the energy usage in a building. This information is considered to be the data base for an energy audit and usually consists of the following elements:

- Building profile – description of plant or building
- Fuel and utility bills – historic energy consumption
- Connected load for each fuel type
- Building survey
- Measurement and consultation
- List of Energy Conservation Opportunities (ECOs)
- Implementation of maintenance and operational changes
- Cost analysis of modifications or energy measures
- Implementation of modifications or energy measures
- Verification of cost and energy savings

There is no single, unique sequence that can be recommended or that is absolutely necessary. The first four items on the list are somewhat interrelated and are developed more or less simultaneously. (Audit forms and checklists are presented in the Energy Audit Workbook.)

Measurements and consultations may or may not prove necessary, depending on the available metering, the quality of information available, and the type of preventative maintenance program and energy conservation program already in existence, if any.

BUILDING PROFILE

Basic facts on the physical plant and its functions should be assembled. Copies of the building site and general layout will be useful and should be obtained from the architect or engineering office. If these are not available, a sketch should be made. For the purpose of the energy audit, the "building" includes a zone of about 5 feet around all sides. It also includes any associated utility (gas, electric, etc.) meters and sub-meters related to the building function. The "site" encompasses all buildings, parking areas, and perimeter lighting.

GENERAL INFORMATION

The name and location of the facility, date of construction, and total floor space (in square feet) should be recorded. A general layout or sketch of the floor plan should show space allotted to various functions. It is useful to begin to think of the plant in terms of the percentage of total space devoted to each function. An estimate of space usage should be made at the outset and refined as necessary. Each functional use of the building will have different purpose patterns and different lighting and ventilating requirements.

POPULATION DENSITY AND ANALYSIS BY DEPARTMENT

After determining what products are made (if any) and how large the staff is, the population density should be estimated by calculating the floor space per employee. Together with the estimate of population density, information should be recorded about hours of operation and energy-consuming processes for each department.

CONSTRUCTION

A thumbnail sketch of the building should be made, indicating the number of glass windows and the building's orientation. This sketch should be accompanied by information about roof or wall insulation and heat-resistant window treatments.

METERS

All gas, electric, steam, and water meters should be recorded for comparison with utility bills. Along with this information should be recorded how the consumption of fuels (such as oil and coal) are monitored and whether a boiler log book is maintained.

EQUIPMENT

All boilers, chiller equipment, hot water generators, kitchen ranges, and other machines, incinerators, or other energy intensive operations should be noted on the floor plan. A more detailed listing of connected load for each energy system input is developed during the site survey.

DATA COLLECTION

An appropriate time period for collecting energy consumption data should be selected. This can be a calendar year, a fiscal year, or any other convenient period of 12 successive months.

Degree-day data for the 12-month period of the audit should be collected (from the local weather bureau) and assembled. This data should include (1) heating degree days below 65°F and (2) cooling degree days above 65°F. This will provide insight on weather-sensitive fuel usage separate from base load or process-sensitive energy usage.

This information should be sorted and stored for use by the auditor. No one person knows where everything is or what it does, but various building functions and energy intensive operations are identified with certain energy requirements. A list of the big energy users (HVAC, lighting, and industrial processes) should be compiled to help identify the scope for energy savings.

FUEL AND UTILITY BILLS

An early step in any energy management program is to obtain all actual utility billings and other fuel consumption and cost data by fuel type for each month of the 12 months preceding. These billings identify rate schedules, fuel adjustment charges, energy charges, monthly consumption, and energy cost.

If actual energy consumption data are not available for the specified period, similar data representing consumption on a calendar or fiscal year basis can be used. If consumption data are not available, it will be necessary to measure the actual consumption for some interval of time, (day, week, or month) and compute an estimate of annual consumption. Utilities have records of bills, and fuel consumption can be reconstructed from their files.

Actual energy consumption should be collected for electricity, natural gas, steam, and water and tabulated for the actual billing period. The billings for all metered utilities will not necessarily coincide and will be assigned for the month in which the greatest number of days occurred. (It is recognized that this technique can cause some inconsistencies. However, there are techniques for correcting these fuel consumptions to whole month periods, should this prove necessary. The utility service representative will be able to assist with such corrections.)

The consumption of fuels purchased during the non-heating season and stored on-site (oil, propane, or coal) requires special consideration. Any record of actual consumption, such as a boiler room log book or records of quantities in inventory, should be searched to establish the actual fuel consumption and cost. The quality of the energy audit depends on how accurately consumption records for these fuels can be reconstructed. If adequate records are not being kept for fuel consumption, the procedure of monthly meter readings and the determination of fuels in storage should be initiated by the energy coordinator.

Suitable forms for recording fuel consumption are given in the Energy Audit Workbook along with step-by-step instructions for filling them out. The object is to first determine an AEI for the facility. All forms of energy are reduced to a common energy basis of millions of Btus (10^6 Btu in scientific notation).

Weather data for heating degree days and cooling degree days should be obtained from the nearest U.S. Weather Bureau. These can be shown graphically for the audit period on forms given in the Energy Audit Workbook. Profiles help identify weather-sensitive energy usage in terms of heating and cooling.

The AEI for a building is derived by dividing the total annual energy consumption in millions of Btu by the gross square feet involved. The AEI for a building will probably be higher in cooler climates, and it will never go to zero because of the building energy usage that is constant throughout the year.

There are no norms for the AEI of various facilities. Figure 1 shows approximately the relation of energy consumption to heating degree days for the AEI of buildings that have no significant large process energy use.

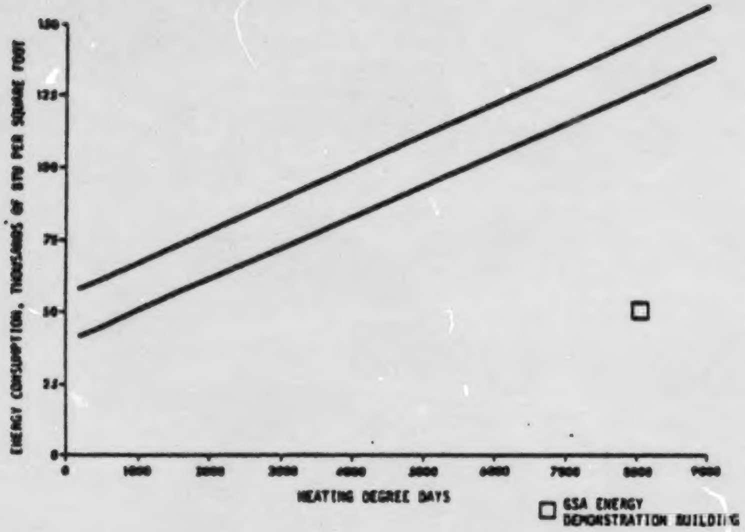


Figure 1. AEI Energy Norms for Buildings.

As a guide for selecting the targets of an energy conservation program, guidelines for interpreting the AEI base savings estimates are conveyed in Table 1.

The AEI of a building varies from year to year, depending on the annual variation in the local climate. There is no simple way to normalize annual energy consumption according to the annual variation in degree days for heating and cooling. However, profiles for the various energy systems can be determined on a month-by-month basis and analyzed with some relatively simple graphical techniques.

A typical profile for monthly energy usage in a die casting plant of about 150,000 gross square feet area is shown in Figure 2. All energy data are shown in common energy units of millions of Btu. The electric energy consumption ranges from 2,000 to 3,000 million Btu per month and is primarily process-related usage, since no weather-sensitive peak was observed for air conditioning in the cooling season.

TABLE 1. GUIDELINES FOR AEI INTERPRETATION.

Location of AEI	Possible Actions Indicated
Above upper norm	Building represents best target for an energy saving program. Be sure variance does not reflect differences in use from "normal" building of this type.
Between upper and lower norms	Building represents a good target for an energy saving program. The closer the estimate is to the lower norm, the more likely capital investment measures will be needed to reduce energy use to the standard level.
Below lower norm	Building may be operating efficiently. Are better targets available? Does the size of the dollar energy budget in this building justify its selection as a target even though percent estimate is low? Is building used less than the normal building of this type?

The profile for natural gas and fuel oil was combined and is shown as total fossil fuel energy. Propane or other alternate fuels used in the plant could have also been combined as total fossil fuel. Each energy type was first converted into the common energy unit of million Btu per month and then summed. The base load fossil fuel consumption is about 5,000 million Btu per month. The profile peaks in December and January and has a curious shift in October. The

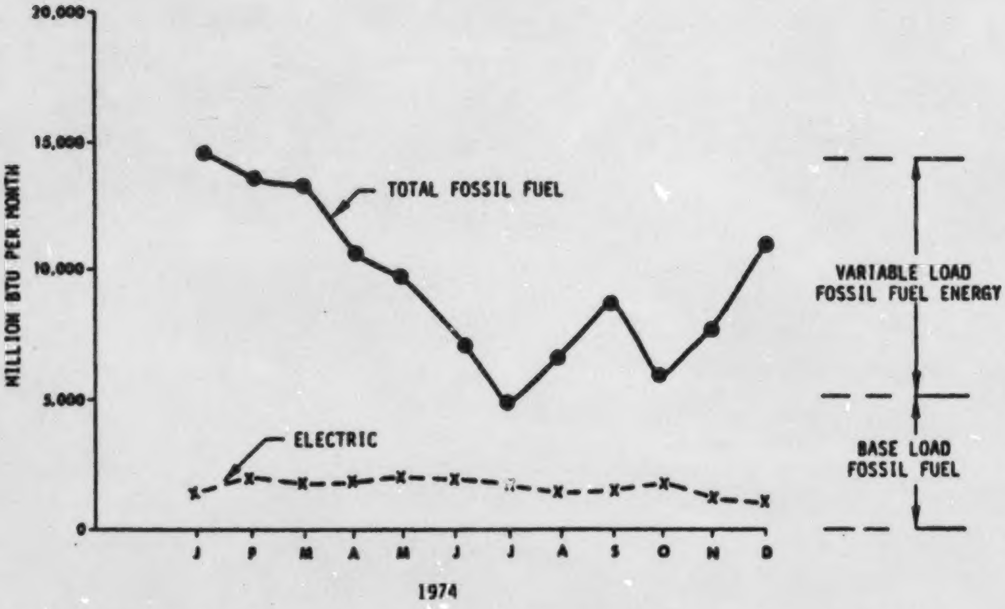


Figure 2. Profile of Energy Usage in a Die Casting Plant.

variable load is the apparent energy for heating needs or weather-sensitive energy consumption and can probably be shown to correlate with the heating degree days below 65°F. The larger portion of fossil fuel energy consumption is, however, process-sensitive energy consumption.

Expressed as Btu, all energy types — including electricity — can be shown on a common graph. It should be remembered, however, that not all Btus were obtained at the same cost. The percent of total Btu input into the plant, which was supplied as electrical energy, should be computed and used as an additional guideline by the auditor. The percent of electric energy consumed should not be allowed to increase in the course of the energy conservation program.

Monthly plant production data were not available. However, plant activity can sometimes be estimated from the data on shipments, assuming there is no substantial change of finished goods in inventory.

A profile of monthly production based on shipments is given for the die casting plant in Figure 3. A decrease in production during the last quarter probably contributed to the October shift in fossil fuel consumption.

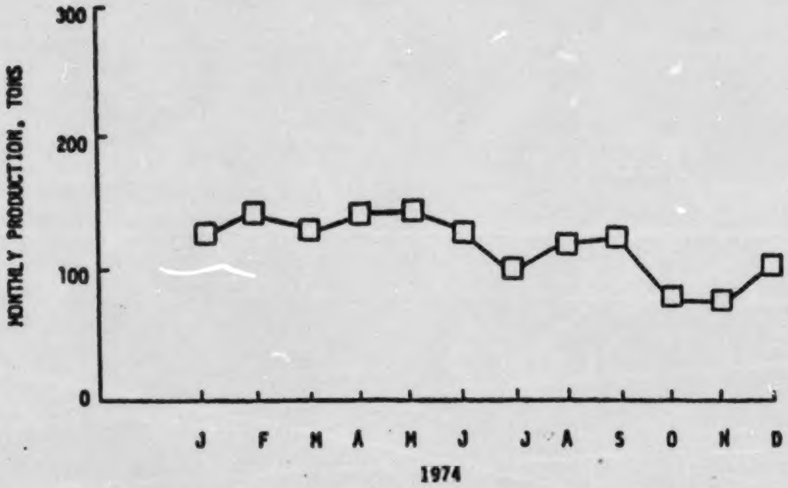


Figure 3. Profile of Monthly Production in a Die Casting Plant (Based on Shipments).

The profile of total fossil fuel energy consumption, as shown in Figure 4, approximately correlates with the heating degree days below 65°F (shown as the dotted line). The departure from the exact correlation can be partially explained by the general shape of the production curve.

The load and production data, collected with sub-meters for energy intensive processes in each department on a monthly basis, make it possible to estimate process-sensitive energy consumption. More accurate measurements of actual energy consumption could be obtained and the overall accuracy of the energy audit improved.

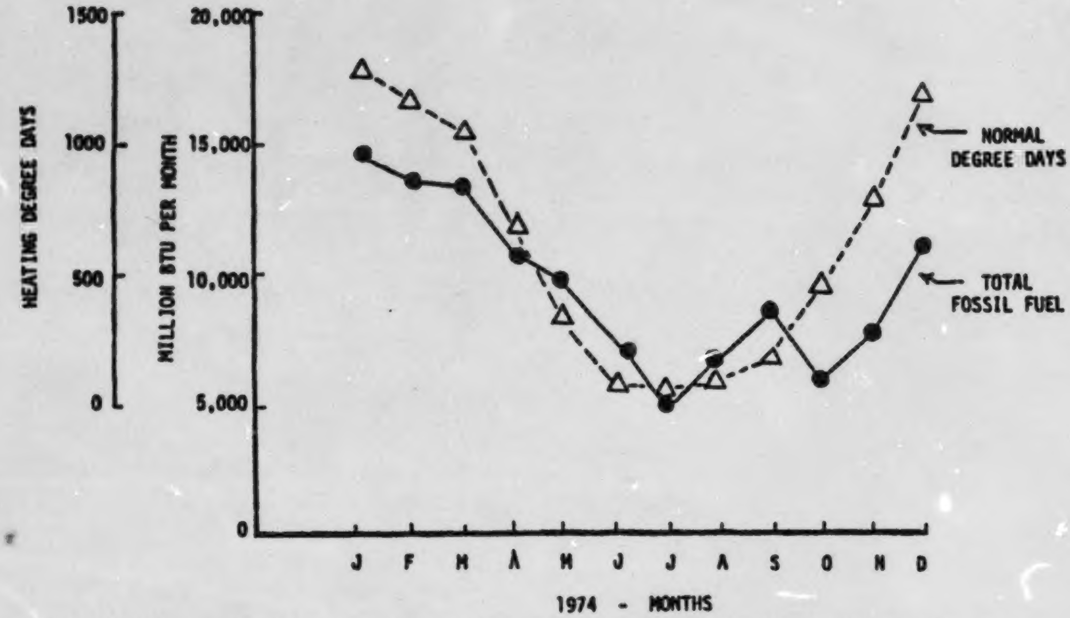


Figure 4. Profile of Fossil Fuel Energy Consumption in a Die Casting Plant (Compared with Heating Degree Days).

EQUIPMENT SURVEY: CONNECTED LOAD FOR EACH FUEL TYPE

The basic facts on the building and physical plant have been discussed earlier in this module, and major energy-consuming systems were noted. However, the auditor should formalize the equipment survey and prepare a connected load diagram for each of the plant's energy supplies.

Shop drawings of the major energy-consuming systems should be studied to determine the size designations and Btu per hour ratings. Boilers should be identified for fuel type and Btu per hour rating. It may be necessary to compute this rating from nameplate data giving cfm of gas or boiler horsepower.

The energy supplies, or energy "streams," should be considered one at a time and the energy use of each should be calculated for a one-month period. The following information should be collected from nameplate data: energy rating (Btu/hour); conversion factor; running hours; and total energy consumed (Btu).

Equation 1 can be used to calculate total energy consumed for each piece of equipment surveyed.

$$\text{Total Energy} = \text{Energy Rating} \times \text{Factor} \times \text{Running Hours} \qquad \text{Equation 1}$$

If the fuel stream is used on only one piece of equipment, such as a space heating furnace, the survey of a connected load is quite simple. However, if the usage is on a number of units of different design or function, suitable metering or instrumentation may be required.

The factors listed in Table 2 can be used as guidelines. The calculations for connected loads are made to determine whether or not the monthly consumption of a given energy stream can be balanced with known loads. If monthly consumption can be balanced to a reasonable extent (± 20% or so), then there is a basis for declaring the possible scope of energy savings for each item on the connected load.

TABLE 2. CONVERSION FACTORS FOR EQUIVALENT BTU VALUES.

Fuel Type	Conversion Factor (Btu per unit)
Anthracite	12,900/lb
Bituminous coal	14,000/lb
Lignite	11,000/lb
Kerosene	134,000/gal
#2 oil	139,000/gal
#4 oil	150,000/gal
#5 oil	152,000/gal
#6 oil (2.5% sulfur)	153,000/gal
Propane	91,600/gal
Natural gas	1,030/ft^3
Electricity	3,412/kWh

In the case of electricity, the problem can be attacked rather simply. To estimate the amount used for lighting, it is necessary only to count the number of bulbs or fluorescent tubes, read off their rating in watts (add 20% for each ballast used with fluorescent), and multiply by the number of hours used per month. The answer will be in watt-hours per month, so divide by 1000 to get kWh. Example A demonstrates the calculation of energy used for lighting.

EXAMPLE A. ENERGY USED FOR LIGHTING.

Given:	Number of bulbs: 200
	Bulb wattage: 75
	Operating hours per month: 310
Find:	Total electricity consumption.
Solution:	$\frac{200 \times 75 \times 1.20 \times 310}{1000} = 5580$ kWh/month

Electric motors offer some difficulty for complete accuracy, but an estimate can be made from nameplate data and estimated use factor. If a motor is labeled at 115 volts and a full load current of 5.5 amperes, it will use 115 V x 5.5 A = 632 watts each hour of operation at full load. Motors seldom operate at full load; 70 percent of full load is a good average. Example B demonstrates the calculation of total energy consumption for the same motor operating at 70 percent of full load.

EXAMPLE B. ELECTRIC MOTOR ENERGY CONSUMPTION.

Given:	Watts per hour: 632
	Hours of operation: 200
	Percentage of full load: 0.70
Find:	Total energy consumption.
Solution:	$\frac{632 \text{ watts} \times 200 \text{ hours} \times 0.070}{1000} = 88$ kWh

For a motor labeled "3 phase," the calculation of watts is voltage times 1.732. For example, a 220-volt, 3-phase motor, rated at a full load current of 2.2 amperes, will use 220 x 2.2 x 1.732, or 838 watts at full load.

Electric heating elements are rated in watts and no correction factor is involved. The kWh usage is simply the wattage times the hours of operation per month, divided by 1000.

In some cases, it may be very difficult to estimate the hours of actual operation, particularly in equipment controlled with a thermostat, such as the compressor motor on an air conditioner or the heating elements on an electric oven. In such cases, it may be necessary to have an electrician connect a simple electric clock across the motor terminals and read the clock every 12 hours for a day or so. The elapsed time, shown on the clock at each reading, will be the hours of operation for the past 12 hours of real time. It must be recognized that this type of measurement is not always representative of a yearly average energy use. For example, the energy demand of air conditioners varies widely with the time of year; the demand pattern of a drying oven may depend wholly on the rate of production.

BUILDING SURVEY

The building survey is a "walk-through" of a facility by the auditor. The purpose is to look for energy waste and determine the total scope for energy conservation. A checklist of Energy Conservation Opportunities (ECOs) may be used as a guide.

Typical questions asked by the auditor include the following:

- Why are lights on in an unoccupied area?
- Why is the hearth operated at less than full load?
- Are there motors running idle?
- When was the last time the heating plant was adjusted for the best air-to-fuel ratio and filters changed or cleaned?

These questions should then lead the auditor to make notes and comments.

Not all ECOs will apply to the facility, and some observations may be made that are not covered by the list. The building survey should emphasize the ECOs that can be implemented as maintenance or operational changes with little or no cost. However, the object is to establish the total scope for energy conservation. Consideration should also be given to evaluating energy measures involving capital expenditures.

The no-cost maintenance and operational changes should be implemented before the payback time for energy measures is computed. In other words, the building should be returned to its designed efficiency of operation before retrofit projects are contemplated.

As the various ECOs are implemented, the AEI value of the building will decrease. There will be a corresponding decrease in the energy output ratio as Btu per pound of product. The need for good record keeping should be emphasized if it is to be a measure of energy savings for an energy conservation program. The recording of utility bills and other fuels should be continued on a monthly basis and compared with the previous year's performance.

AUDITORS, ENERGY CONSERVATION PROGRAMS, AND TOTAL ENERGY MANAGEMENT

Because of their "hands-on" relationship with the facilities being audited, energy auditors are in a good position to get energy conservation programs started. The auditor has access to raw data from both records and measurements. This data, together with a thorough survey of the facility, enables the experienced auditor to determine the major areas of energy loss, recommend modifications which will reduce these losses, and emphasize (to facility owners/operators) the effectiveness of total energy management.

MAINTENANCE AND OPERATIONAL CHANGES

A qualified and experienced auditor is aware of the no-cost energy efficiency modifications that can save significant amounts of energy and retain acceptable levels of comfort and safety for a facility's occupants. Most facilities can yield a 15% or greater reduction in energy consumption if operational changes are made conscientiously. These changes include running boilers at best efficiency, keeping indoor temperatures at 68°F or lower in winter and 78°F or higher in summer, turning off unnecessary lights, and other obvious but frequently overlooked energy saving opportunities.

SIMPLE PAYBACK

Given an energy measure that costs A dollars to implement and that is expected to save B dollars each year at today's prices, the simple payback is A divided by B years. The purist will immediately question whether the time value of money should be considered. The answer is, "Of course, if one truly wants to know the payback period." The question that is being faced here, however, is: Which measures should be implemented and in what order? Inasmuch as a fixed discount rate (10%) has been decreed, the simple payback time will rank the measures in the same order as the discounted payback calculation. Thus, no significant information is lost by not utilizing the discounting procedures common to payback calculations.

If the auditor has good first-cost information along with an accurate description of the annual expected savings, the procedures set forth in "Life-Cycle Costing Emphasizing Energy Consumption, Guidelines for Investment Analysis," ERDA-76/130, revised May 1977, should be followed. The auditor is encouraged to be aware of these procedures should the need arise for their implementation.

PRIORITY RANKING OF MEASURES

Several measures from each facility can be readily ranked by the auditor if the payback periods have been calculated. (Caution: More than one payback period technique should not be used since each technique yields different results.) The shortest payback period indiactes the most cost-effective measure in a group of measures. It may be that the most cost-effective measure is neither the most energy saving nor the least expensive measure. Therefore, some judgment may modify the ranking, but the shortest payback period is the best general approach to top ranking in the long run.

IMPLEMENTING ENERGY MEASURES

The facility is responsible for implementation of energy-saving measures. The auditor may assist in the ranking and provide technical advice, but the site management must execute the project. Follow-up audits should be made to assist management in ensuring that energy savings exist and that they are not lost in facility use changes. For instance, a 15% expected saving for a boiler change could be apparently wiped out by a 15% increase in heating degree days during the next season. If a proper audit is conducted, the oil consumption per degree day will be lower and, thus, account for the improved efficiency. A key aspect of implementation is an ongoing audit and continuous record keeping.

The auditor can materially aid the facility by providing the quick training and guidance needed to permit the facility to chart its savings course in the future.

TOTAL ENERGY MANAGEMENT

In order to overcome the problems of end-use restrictions and thereby establish the basis for far more meaningful energy conservation programs, private industry and government together helped formulate a new conservation method called Total Energy Management (TEM).

The ultimate objective of the TEM program is to bring a building's systems to peak efficiency and to maintain that efficiency through continuing management efforts.

TEM considers every building or complex of buildings as a unique entity. To best understand how to conserve energy, TEM holds that one first must understand how it is consumed and the interrelationships of the various systems, sub-systems, and so forth. Once this understanding is obtained, administrative, health care, and technical personnel are able to collaborate to determine where, when, and how modifications should be made to reduce consumption. Implementation of modifications and the overall TEM program itself then becomes the responsibility of administrative personnel to ensure realization of energy conservation goals.

Although there are literally hundreds of specific TEM options available, the overall concept of the TEM program is to improve energy efficiency of all building systems, subsystems, and components. Implementing this concept has three primary effects. First, it eliminates energy wastage. Second, it significantly expands areas of investigation. This expands opportunities for conservation while also providing a substantial amount of flexibility so management can select the option desired.

Close examination shows that TEM essentially is two old wines mixed in one new bottle. The management techniques recommended are essentially similar to those employed in any well-run organization. Likewise, many of the TEM energy conservation options suggested are relatively conventional. What is important is the fact that the technical and management aspects of energy conservation are integrated and that so many different energy conservation options have been interrelated with one another.

TEM's impact already is being felt in buildings across the nation. In the case of buildings that have not been subjected to other conservation efforts, energy savings of 15% to 20% and more in the first year of TEM application have been documented. Frequently, many of the measures used to achieve these savings require very little capital investment. In cases where capital investment is required, payback generally is three years or less. As the cost of energy increases, of course, these payback periods will become shorter. Perhaps most important, however, is the fact that TEM can achieve substantial energy and energy cost savings without disruption to the many working environments which modern facility systems must support.

EXERCISES

1. List, compare, and contrast the major types of audits.
2. List and define (in no more than two sentences each) the elements of the "data base" for an energy audit.
3. Define the AEI and briefly discuss how it is used by the auditor.
4. List the information necessary to calculate the total energy consumed by a piece of equipment.
5. Convert a total consumption of 9,876,600 watt-hours to kWh.
6. If a motor consumes 700 watts per hour at full load, what energy consumption figure would the auditor use in estimating actual energy usage?
7. Define simple payback, discuss it briefly, and include in the discussion the ways in which the auditor can make use of it.

REFERENCES

Instructions for Energy Auditors, Vol. I. Springfield, VA: NTIS, Sept. 1978. (DOE/CS-0041/12).

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Texas Energy Auditor Training Manual, 1980. Austin, TX: Texas Energy and Natural Resources Advisor Council, 1980.

Total Energy Management for Hospitals. Hyattsville, MD: Department of Health, Education and Welfare (Pub. # 78-613).

Thumann, Albert. Handbook of Energy Audits. Atlanta: The Fairmont Press, 1979.

Washington Energy Auditor Instructor Training Manual. Olympia, WA: Washington State Energy Office, 1979.

Multiple Choice. For Questions 1-4, choose the answer closest to the correct one by circling the appropriate letter.

1. What is the total monthly electricity consumption of 196 incandescent light bulbs rated at 60 watts each, operating 310 hours per month?
   a. 4176 kWh
   b. 3647 kWh
   c. 4375 kWh
   d. 3923 kWh
   e. 3214 kWh
2. What is the total monthly electricity consumption of 75 fluorescent light tubes rated at 40 watts each, operating 720 hours per month? (Remember to include ballast consumption.)
   a. 1949 kWh
   b. 2419 kWh
   c. 2160 kWh
   d. 3019 kWh
   e. 2592 kWh
3. What is the total monthly electricity consumption of a motor that is labeled 115 volts, 6.5 amps, operating 150 hours per month? (Remember that motors do not always run at full load.)
   a. 78 kWh
   b. 87 kWh
   c. 72 kWh
   d. 81 kWh
   e. 76 kWh

4. What is the simple payback period for an energy conservation measure that costs $9,152 to implement and reduces the annual electricity consumption of a facility by 14,500 kWh in an area where the charge per kWh is $0.05?
   a. 10.2 years
   b. 12.6 years
   c. 11.2 years
   d. 14.6 years
   e. 12.1 years

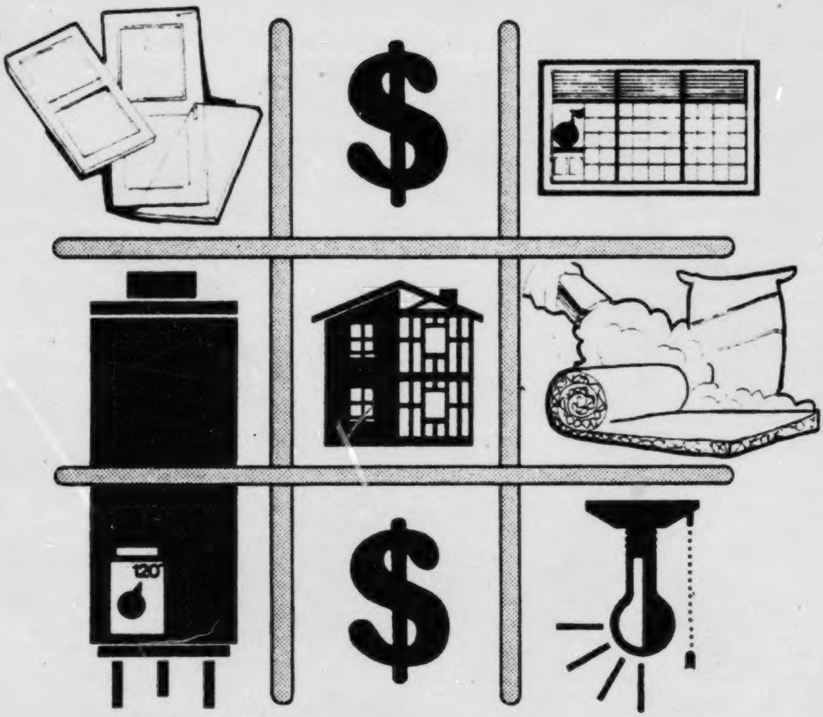
True or False. Enter true or false in the blank at the end of Questions 5-10.

5. The mini-audit requires no tests or measurements. _____
6. Population density is estimated by calculating the floor space per employee. _____
7. The preliminary information an auditor collects need not include actual utility billings. _____
8. To calculate the AEI, all forms of energy must be converted to kWh. _____
9. There are as many Btus in 79 kWh of electricity as there are in 1.9 gallons of #2 oil. _____
10. A 220-volt, 3-phase motor, rated at a full load current of 2.5 amperes, consumes 915 watts at full load. _____

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY AUDITS



MODULE EA-04

BUILDING SYSTEMS

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

The building envelope is the major non-energized energy use system. The building envelope is composed of all external surfaces that are subject to climatic impact and internal barriers to heat flow. This module discusses air infiltration and exfiltration, solar heat gain and loss through the major components of the envelope, and internal heat flow. R values and U values are discussed and the methodology for calculating them is explained.

PREREQUISITES

The student should have completed Module EA-03, "Energy Audit Process and Analysis."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Discuss air infiltration and exfiltration, heat gain, heat loss, and heat flow as they impact on the entire building energy use system.
2. Explain and calculate R values and U values.
3. Discuss practices that improve energy efficiency of building operation without maintenance or retrofit.
4. List and discuss operation/maintenance and retrofit measures for improving energy performance of the building envelope.

BUILDING SYSTEMS: TOTAL ENERGY MANAGEMENT

The energy required in all types of buildings to provide proper environmental conditions (temperature, humidity, light, and fresh air) involves not only mechanical systems and services within the facility, but also the building envelope. The building envelope contains the man-made environment and excludes often-adverse outside conditions.

Total energy management, therefore, must incoporate all possible ways that conductive and convective heat losses and gains (outdoors-to-indoors and indoors-to-outdoors) can occur each season through the building envelope. The energy management technician must also consider solar heat gains – helpful in winter and unwanted in summer. And, because of functional complexities, energy management should also extend to the separation of environmental zones inside the building envelope.

THE ENERGY AUDIT

A total energy management program must begin with a thorough energy audit of the building and its systems – not the least of which is the building envelope. The first step of an audit is to examine all physical conditions of the building that are subject to heat transfer.

All the items found in the basic audit – whether or not in need of repair or installation – should be scheduled for re-examination on an appropriate periodic basis so that cost-effective and energy-effective maintenance is achieved.

This scheduling may be computerized as part of the overall building's energy management program. In that way, the conditions and effects of the building envelope become part of the monthly energy consumption analysis.

CONSERVATION OPPORTUNITIES

There are many small ways to conserve energy in the building envelope, as well as larger, more expensive improvements that can be made. It is important to put these opportunities into some overall perspective. From the broad point of view, there are five major areas of concern. They follow, in order of importance, for existing building considerations:

- Reduction of infiltration and exfiltration
- Reduction of solar heat gain through windows
- Reduction of heat loss through windows
- Reduction of heat gain and loss through walls, roofs, floors, and slabs
- Reduction of internal heat transfer

A general analysis of each of these five subjects is presented in the discussion that follows. Some specific conditions are cited, but a more complete list of possible steps in energy conservation – especially for the many small efforts that add up to meaningful savings – is provided in the Energy Conservation Checklist section of the Energy Audit Workbook.

INFILTRATION AND EXFILTRATION

The need for a large portion of the energy used for heating and cooling a typical building results from the heat gains and losses through the building envelope. In the typical building, the major portion of that loss or gain occurs as infiltration and exfiltration (air leakage through all kinds of cracks and crevices in the building envelope).

Outside air can leak through cracks around operative window sashes and doors, between the door or window frames and the wall materials in which they are set, and through joints in the basic wall construction – especially in panelized wall systems.

BUILDING EXTERIORS

There are many types of building exterior treatments; chances for leakage in and out of the building envelope vary accordingly. For example, consider the increasing amount of crack-footage in the following list of facade types:

- Individual windows set in brick walls
- Bands of windows set in brick walls
- Precast panel systems; windows in some panels
- Curtain wall treatment on two sides only
- Curtain wall treatment on all four sides

At the same time, consider the quality of the installation and the caulking materials used. Quality of installation can vary from good to poor, and caulkings can change in quality with age. Fortunately, most curtain wall systems have good details for holding glass and for preventing leakage.

Infiltration and exfiltration vary with wind velocities and wind pressure (both positive and negative) on different sides of the building. Air pressures inside the building envelope can also be positive and/or negative. Wind and air pressures can combine with exterior conditions to induce leakage when the potential exists.

STACK EFFECT

There is also a stack effect in tall buildings, especially in vertical spaces like stairways, elevators, and mechanical service shafts. Warm air rises. So, when outside air is cold, there is a strong potential for infiltration on bottom floors and exfiltration at top floors.

CAULKING AND WEATHER STRIPPING

Caulking between fixed systems and weather stripping movable window sashes and doors are major means of reducing infiltration and exfiltration in the building envelope. There are probably as many types of caulking and weather stripping materials as there are types of cracks to be filled. In general, the non-hardening, surface-skinning types of caulkings are best. Caulkings must have permanent adherence and should be chosen according to surfaces involved. These surfaces must be clean and dry. For wide cracks, a filler (or backer-rod) can be used before caulking. Weather stripping includes compressible, closed-cell foam; compressible tubular systems; and interlocking metal-strip systems. Since there are many conditions that can exist for caulkings and weather stripping, it is wise to get expert advice on the subject.

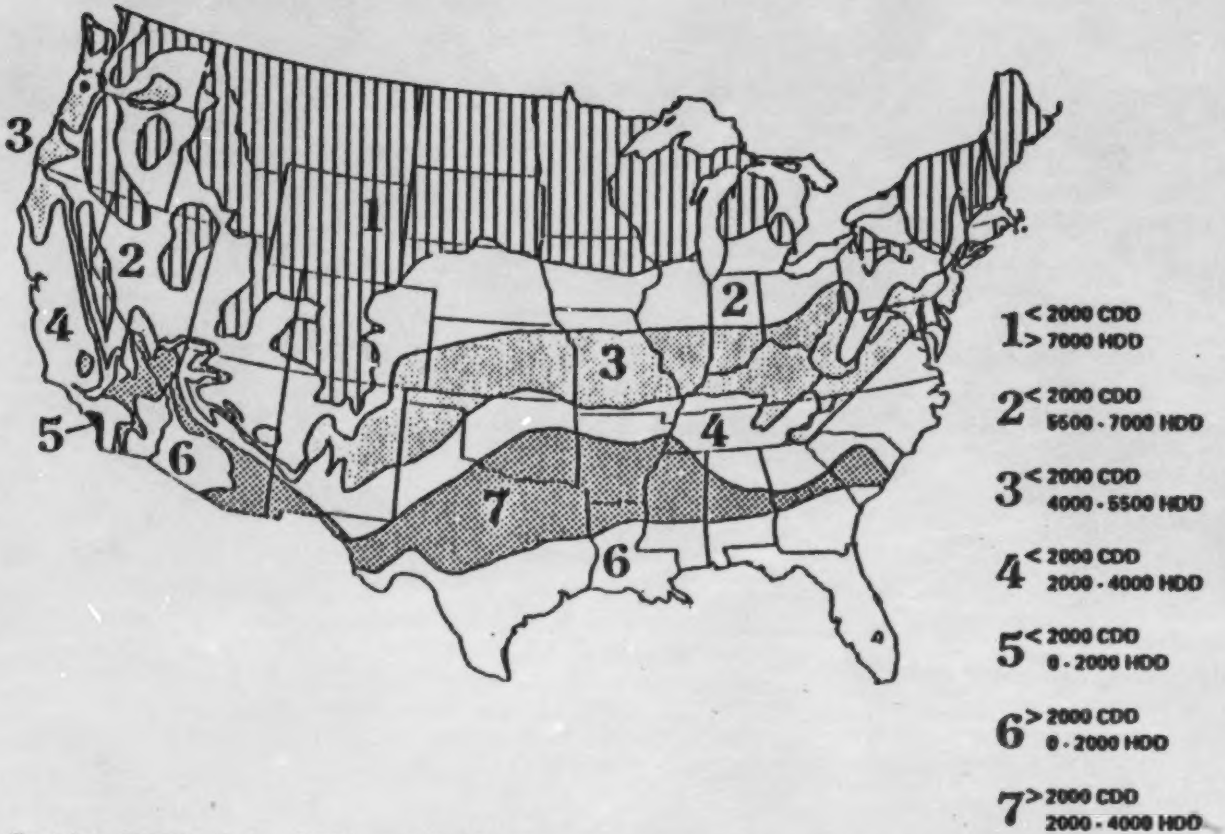
STORM WINDOWS

Storm windows are often used to increase thermal resistance through glass. Double glazing is also used for this purpose. However, storm window units generally have an advantage: increased control over leakage of air around window frames. Depending on window framing and installation details, storm windows in secondary frames are usually more energy-conserving than double glazing in a single frame, and storm windows are often easier to use in existing conditions.

SOLAR HEAT GAIN

Heat gains from solar radiation through windows in Texas buildings can have a major impact on energy use, depending on factors like orientation, exposure and shading, winter and summer, types of glass, and glass treatment. Tennessee, on the other hand, is located where winters are moderately cold; the need for cooling to overcome heat gain through windows in summer is comparable to the benefit of heat gain in the winter. To compare heating and cooling requirements for various areas in the United States, see Figure 1, "Climatic Zones."

There is so much more heat gain from solar radiation than from conduction through the glass that radiative gains


1
2
3
4
5
6
7
0
1 < 2000 CDD > 7000 HDD
2 < 2000 CDD 5500 - 7000 HDD
3 < 2000 CDD 4000 - 5500 HDD
4 < 2000 CDD 2000 - 4000 HDD
5 < 2000 CDD 0 - 2000 HDD
6 > 2000 CDD 0 - 2000 HDD
7 > 2000 CDD 2000 - 4000 HDD

Heating Degree Days (HDD) and Cooling Degree Days (CDD): This is the average of the daily maximum or minimum temperatures of any given day. The degree day value for any given day is the difference between 65 degrees and the mean daily temperature. Example: Mean daily temperature of 50 degrees — the degree days are 65 minus 50 degree days. They measure the severity of the entire season.

Figure 1. Climatic Zones.

must be considered before conductive heat transfer through the glass is considered. When double glazing is determined to be the best approach for reducing summer heat gains, there will also be a benefit in controlling heat losses in the winter season.

ORIENTATION

The effects of building orientation are different for winter and summer. In winter, the sun rises a little south of east, is low in the south sky at noon, and sets correspondingly south of west. This sun movement allows some east and west wall solar heat gain in the morning and afternoon, respectively, and a lot of midday sun on the south walls and into south-facing windows. In the summer, the sun rises a little north of east and sets a little north of west. At noon, the sun is high overhead, barely shining on southerly walls and windows. Summer solar radiation, therefore, is more severe on east and west exposures and not so serious on southern exposures. North-facing walls and windows get no sunshine in the winter and only early morning and late afternoon angular exposure to summer sun.

EXTERIOR SHADING

Exterior architectural shading for windows must relate to these sun angles. On east and west elevations, such devices must be vertical, the full height of the windows, and sometimes adjustable for the actual orientation and time of day. For south-facing windows, roof overhangs and projecting horizontal "eyebrows" over each band of windows can give shade in summer yet allow winter solar gains. When used, such shading devices are usually part of original design and construction. They are only occasionally installed on existing structures.

External shading devices are the most effective method of controlling solar heat gain because they prevent the sun from shining directly on the glass. There are some external sunshading devices available that can be fixed to the window openings, and that provide meaningful shading. Sometimes, these devices can be removed or adjusted to allow winter solar heat gain.

INTERNAL SHADING

Internal shading devices include drapes, venetian blinds, vertical louver blinds, roller blinds, and variations of these basic types. While less effective than other methods of solar heat gain, internal shades are relatively inexpensive and are more easily adjustable to solar gain, light, and view considerations.

WINDOW GLASS TREATMENTS

Tinted or reflective glass, and reflective polyester films applied to the inside of the glass, may also be used to reduce solar heat gain. Tinted or reflective glass can be used to replace existing glass or to create double glazing (storm windows). Films are self-adhesive, but require care in application. Film should be on the inner face of the outside layer of glass on storm windows. (If film is put on the inner glass, reflected heat will be trapped).

An example of solar heat gain reduction involves the application of reflective solar film to 10,000 square feet of east, south, and west windows in a 10-story office building in Miami, Florida. The annual energy savings calculated was 15% – with a payback of just over two years.

In winter, solar heat gain is beneficial. The usefulness of winter solar heat gain must be balanced against summer solar gains according to orientation, types of glass, reflective films, latitude, solar control devices, and percentage of sunshine. Note that about 10% less sunlight penetrates double glazing than single glazing. However, double glazing reduces the heat load due to conduction; the benefits from this more than offset the loss of solar radiation.

HEAT LOSS THROUGH WINDOWS

On the national scale, it has been estimated that 20% of energy goes to space conditioning in buildings. Of this, 25% results from heat losses and gains due to the relatively high thermal conductivity of windows – an energy use equivalent to an average of 1.7 million barrels of oil per day.

U VALUE

The rate of conductive heat flow through various parts of the building envelope (glass, walls, roof, floors, and so forth) is expressed as a U value. This rating is in units of Btus/hour/square foot of surface/°F of temperature difference inside to outside. The lower the U value, the higher the insulating value of the construction rated. Typical wall and roof constructions vary from U = 0.4 to U = 0.04, depending on the basic structural materials and the type and thickness of the insulation used. Single panes of glass in still air (less than 15 mph) have a U value of 1.13. Double glazing reduces the U value to about 0.55.

These values show a greater concern for heat flow through glass than through the solid parts of the building envelope (exterior walls, roof, and floors over unheated space). It is helpful to put this difference into some sort of perspective. This is done by comparing U values to what would be equivalent areas for the same transmission of Btus per hour.

Assume the following reasonable U values for two windows (based on Table 1) and a wall:

a. Windows with single glass: 1.1 U value
b. Window with double glass: 0.55 U value
c. The solid wall: inside = gypsum board
    insulation = R-17
    wall = 0.055 U value
    exterior = sheathing plus wood panel, painted

TABLE 1. U VALUES FOR GLASS.

Glass	U Value
Single pane	1.13
Double pane	0.65
Triple pane	0.47
Storm window and air space	0.56

The rate of heat flow through the solid wall is one-tenth that of the double glazed window, which in turn is one-half that of the single glass. Since this transmission rating is on a square-foot basis, the same amount of heat would be transmitted through:

a. Single glass window: 2.5' x 4' = 10 sq ft
b. Double glazed window: 5' x 4' = 20 sq ft
c. Solid wall: 10' x 20' = 200 sq ft

Using double glazing reduces the conductive heat loss of single glazing by one-half. However, this will occasionally be modified by solar radiation and wind, and, therefore, by orientation. Wind destroys the exterior air film on the glass; this causes the U value of the window to increase. Shutters, screens, trees, and other shielding devices reduce this wind effect.

It is often easier to add storm windows to existing windows than it is to change to double glazing in the original frame. The choice will vary with the physical conditions, the present needs and replacement plans, and so forth, for each building. The use of storm windows provides greater reduction in heat transfer through the windows because of greater air space. Storm windows give more control over air infiltration because of the second frame set tightly in the window opening.

MEAN RADIANT TEMPERATURE

The use of the various types of drapes, blinds, and appropriate linings to cover windows not needed for light or view also helps reduce heat flow through windows. An added advantage provided by the drapes is that they improve the mean radiant temperature in a room or office. That is, the occupant often will not feel the cold window in the winter or window heat in the summer. Eliminating this human response to radiant heat flow toward or from glass precludes the occupants' need for more heat or more cooling for comfort.

When rooms or zones of the building are unused or closed off, thermal transmission through the windows, in both winter and summer, can be meaningfully reduced by closing off the windows with various types of thermal barriers. Depending on the time the space is to be closed off, and on how the space heating and cooling is to be maintained, the thermal barriers can range from simple drapes and blinds to storm windows or opaque, insulated panels.

HEAT FLOW THROUGH WALLS, ROOF, AND FLOORS

R VALUE AND U VALUE

Energy conservation efforts must take into account the rate of conductive heat flow through various types of building construction. This is the U value of each complete construction (inside-to-outside) including air films, as discussed above. If heat flow is to be reduced, the R value (or thermal resistance) of materials like insulation, masonry, wood, or plaster must also be considered. In computing for energy conservation purposes, the R value of all materials in a wall construction is totaled. The result, or total R value, is the reciprocal of the U value of the whole construction.

This relationship of the U value to the total R value, and then to the R values of the parts of a construction, is meaningful in discussing improvements that might be achieved by the addition of certain insulation materials. Insulation materials are commercially rated by their R values, even though the U value is commonly used as a rating of the total construction.

It is best to remember that, simply put:

- The higher the R value, the better the insulation of the material.
- The lower the U value, the better the insulation of the whole construction.

For most wall and roof constructions, individual structural materials are inadequate as thermal barriers because various amounts and types of insulation are included in their design. The physical examination of a building envelope during a basic energy audit should include an analysis of the plans, details, and specifications of building construction. This analysis will determine the resistance to heat flow of the building's parts. This analysis should also be done for the various details of wall and roof construction — and for any floors over unconditioned spaces.

Variables include latitude, solar radiation, degree hours above 80°F, winter degree days, building and wall orientation, surface heat absorption coefficients, seasonal wind patterns and velocities, as well as the theoretical U value of each construction. See Table 2 to compare heat loss through roof and Table 3 to compare heat gain through roof for selected cities in the United States.

The mass of a wall does not give it a better or lower U value, per se. Mass simply provides a form of thermal inertia: it slows up heat transfer and delays the impact of outdoor temperature changes on inside conditioned space. The time delay allows the wall to act dynamically as a thermal storage system, smoothing out peaks in heat flow and somewhat reducing yearly heat loss. High mass walls of 80 to 90 lbs/sq ft have approximately 2% less yearly heat loss (or gain) than low mass walls of 10 to 20 lbs/sq ft, assuming the same U value and absorption coefficient for both walls.

TABLE 2. YEARLY HEAT LOSS/SQUARE FOOT THROUGH ROOF.

City	Latitude	Solar Radiation Langleys*	Degree Days	Heat Loss Through Roof Btu/Ft^2 Year			
				U=0.19		U=0.12	
				a=0.3	a=0.8	a=0.3	a=0.8
Minneapolis	45°N	325	8,382	35,250	30,967	21,330	18,642
Concord, N.H.	43°N	300	7,000	32,462	27,678	19,649	16,625
Denver	40°N	425	6,283	26,794	22,483	16,226	13,496
Chicago	42°N	350	6,155	27,489	23,590	16,633	14,190
St. Louis	39°N	375	4,900	20,975	17,438	12,692	10,457
New York	41°N	350	4,871	21,325	17,325	12,911	10,416
San Francisco	38°F	410	3,015	10,551	8,091	6,381	4,784
Atlanta	34°N	390	2,983	12,601	9,841	7,619	5,832
Los Angeles	34°N	470	2,061	4,632	3,696	2,790	2,142
Phoenix	33°N	520	1,765	5,791	4,723	3,487	2,756
Houston	30°N	430	1,600	6,045	4,796	3,616	2,778
Miami	26°N	451	141	259	130	139	55

*The langley is a measure of radiation intensity. One langley equals 3.68 Btu per square foot.

TABLE 3. YEARLY HEAT GAIN/SQUARE FOOT THROUGH ROOF.

City	Latitude	Solar Radiation Langleys*	D.B. Degree Hours Above 78°F	Heat Loss Through Roof Btu/Ft^2 Year			
				U=0.19		U=0.12	
				a=0.3	a=0.8	a=0.3	a=0.8
Minneapolis	45°N	325	2,500	2,008	8,139	1,119	4,728
Concord, N.H.	43°N	300	1,750	1,891	7,379	1,043	4,257
Denver	40°N	425	4,055	2,458	9,859	1,348	5,680
Chicago	42°N	350	3,100	2,104	7,918	1,185	4,620
St. Louis	39°N	375	6,400	4,059	12,075	2,326	7,131
New York	41°N	350	3,000	2,696	9,274	1,543	5,465
San Francisco	38°N	410	3,000	566	5,914	265	3,354
Atlanta	34°N	390	9,400	4,354	14,060	2,482	8,276
Los Angeles	34°N	470	2,000	1,733	10,025	921	5,759
Phoenix	33°N	520	24,448	12,149	24,385	7,258	14,649
Houston	30°N	430	11,500	7,255	20,931	4,176	12,369
Miami	26°N	451	10,771	9,009	24,594	5,315	14,716

*The langley is a measure of radiation intensity. One langley equals 3.68 Btu per square foot.

INSULATION

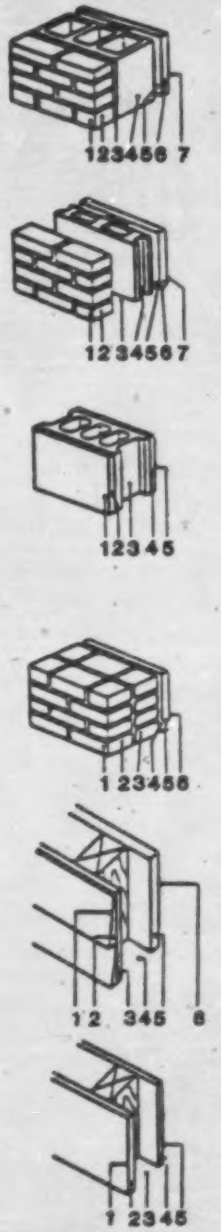
When it is determined that the U value of a wall should be lowered as an energy conservation measure, the first consideration should be to increase the wall insulation. It is seldom possible to do this without going to some extreme measures, such as removing the interior wall surfaces (often gypsum board or plaster) and then adding appropriately high R value insulation before resurfacing the wall.

Exterior Facing

It is also possible to add insulation with a new facing over existing surfaces. When added to the exterior, the treatment will have to be weather-sealed and vapor-proofed, and it will give an entirely new look to the building unless a similar facing existed before. Such exterior treatment is feasible for low-rise structures, but difficult for tall buildings. It has the practical advantage of causing little disruption inside the building.

Interior Facing

Interior treatment is easier in tall buildings, but is disruptive to normal operations. In both interior and exterior treatments, there are likely to be architectural and mechanical complications not readily discernable. There are usually building code conditions to consider. Therefore, it is advisable to get professional help. See Figure 2, "U Values for Typical Wall and Roof Construction (Walls)."



Construction	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Face brick (4 in)	0.44
3. Cement mortar (1/2 in)	0.10
4. Concrete block (cinder agg) (8 in)	1.72
5. Air space (reflective)	2.80
6. Gypsum wallboard, foil back (1/2 in)	0.45
7. Inside surface (still air)	0.68
Total resistance	6.36
U = 1/R = 1/6.36 =	0.16

Construction	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Common brick (4 in)	0.80
3. Air space	0.97
4. Concrete block (stone agg) (4 in)	0.71
5. Air space	0.97
6. Gypsum wallboard (1/2 in)	0.45
7. Inside surface (still air)	0.68
Total resistance	4.75
U = 1/R = 1/4.75 =	0.21

Construction	Resistance (R)
1. Inside surface (still air)	0.68
2. Plas. (lt wt agg) 5/8 in	0.39
3. Cement block (cinder agg) (4 in)	1.11
4. Plas. (lt wt agg) 5/8 in	0.39
5. Inside surface (still air)	0.68
Total resistance	3.25
U = 1/R = 1/3.25 =	0.31

Construction	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Face brick (4 in)	0.44
3. Common brick (4 in)	0.80
4. Air space	0.97
5. Gypsum wallboard (1/2 in)	0.45
6. Inside surface (still air)	0.68
Total resistance	3.51
U = 1/R = 1/3.51 =	0.29

Adjustment for furring (1 x 2 in @ 16 in o.c.)
= U_1 x 1.00 = 0.29 x 1.00 = 0.29

Construction	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Siding, wood, 1/2 x 8 in lapped (avg)	0.81
3. Sheathing, 1/2 asphalt impregnated	1.32
4. Air space	0.97
5. Gypsum wallboard (1/2 in)	0.45
6. Inside surface (still air)	0.68
Total resistance	4.40
U = 1/R = 1/4.12 =	0.23

Construction	Resistance (R)
1. Surface (still air)	0.68
2. Gypsum bd (1/2 in)	0.45
3. Air space	0.97
4. Gypsum wallboard (1/2 in)	0.45
5. Surface (still air)	0.68
Total resistance	3.23
U = 1/R = 1/3.23	0.31

Figure 2. U Values for Typical Wall and Roof Construction (Walls).

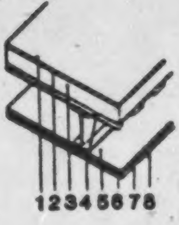
Roof Insulation

Heat gain and loss through roofs can also be reduced by lowering the U value by adding insulation. Again, there are techniques for this additional treatment both on top and on the underside of the roof.

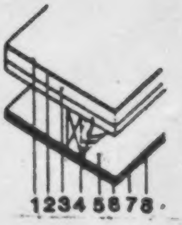
When adding insulation to the top of the roof, work is less disruptive and may be done when the existing surface needs repair. The surface must be prepared according to the techniques employed. Both sprayed foam and rigid board insulation are available for use on roofs. Each has a treatment for a new top waterproof surface. When the existing roof is acceptable, especially with a new built-up roof, the new IRMA roof system of Dow styrofoam may be appropriate, since insulation is laid over waterproofing, shielding it from the sun's heat. A professional consultant should be sought.

Insulation below the roof structure may be applied to the underside of that structure by spray application or with fitted pieces of insulation board. One must work above and around existing utility lines, pipes, ducts, and structural members. The need for insulating the pipes, ducts, and so forth, should not be overlooked – nor should their location in the attic space allow some area of the roof underside to go untreated. If insulation is laid over the existing ceiling, it is important to consider pipe and duct insulation and, possibly, the need for attic ventilation.

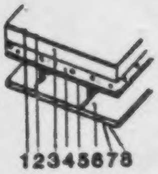
As a rule of thumb, the thickness of duct insulation required is one-fifteenth of the temperature difference between the conditioned air inside the duct and the unconditioned air in the attic space. See Figure 3, "U Values for Typical Wall and Roof Construction (Roofs)."



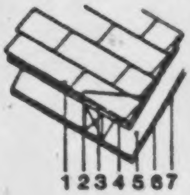
Construction	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Built-up roofing (3/8)	0.33
3. Roof insulation (C = 0.24)	4.17
4. Metal deck	0.06
5. Air space	0.99
6. Metal lath and	
7. 3/4 in plas. (san agg)	0.13
8. Inside surface (still air)	0.92
Total resistance	6.71
U = 1/R = 1/6.71	0.15



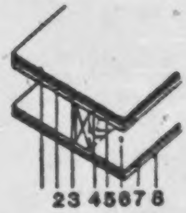
Construction (Heat flow up)	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Built-up roofing (3/8 in)	0.33
3. Roof insulation (C = 0.72)	1.39
4. Plywood deck (5/8 in)	0.78
5. Air space	0.85
6. Gypsum wallboard (1/2 in)	0.45
7. Acoustical tile (1/2 in) — glued	1.25
8. Inside surface (still air)	0.61
Total resistance	5.83
U = 1/R = 1/5.83	0.17



Construction (heat flow up)	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Built-up roofing — 3/8 in	0.33
3. Roof insulation (none)	—
4. Concrete slab (lt wt agg) (2 in)	2.22
5. Corrugated metal	0
6. Air space	0.85
7. Metal lath and 3/4 in plas. (lt wt agg)	0.47
8. Inside surface (still air)	0.61
Total resistance	4.65
U = 1/R = 1/4.65 =	0.22



Construction (Heat flow up)	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Asphalt shingle roofing	0.44
3. Building paper	0.06
4. Plywood deck (5/8 in)	0.78
5. Air space (3.5 in. reflective surface)	2.06
6. Gypsum wallboard (1/2 in)	0.45
7. Inside surface (still air)	0.62
Total resistance	4.38
U = 1/R = 1/4.38	0.22



Heated room below unheated space

Construction (heat flow up)	Resistance (R)
1. Top surface (still air)	0.61
2. Linoleum or tile (ave R)	0.05
3. Felt	0.06
4. Plywood (5/8 in)	0.78
5. Wood subfloor (3/4 in)	0.94
6. Air space	0.85
7. Metal lath and 3/4 in plas (lt wt agg)	0.47
8. Bottom surface (still air)	0.61
Total resistance	4.37
U = 1/R = 1/4.37 =	0.23

Figure 3. U Values for Typical Wall and Roof Construction (Roofs).

Floor Insulation

When floors over unconditioned spaces (crawl spaces, vented and unvented; pipe and mechanical spaces, rough storage spaces; outdoor spaces) are deemed to have inadequate resistance to heat flow, the U value can also be lowered by the addition of insulation materials. Types of treatment vary with accessibility. Again, treatments include spray applications and rigid board treatment.

When additional insulation is required for floors poured at ground level, insulation can be installed as an exterior, perimeter treatment. (For example, Dow styrofoam, fiberglass, and so forth, might be applied.) Insulation board can be placed against the foundation. All on-grade floor insulation is applied from the bottom of the exterior wall facing down to a point approximately 24 inches below grade.

INTERNAL HEAT FLOW

Buildings are often very complex facilities that must house many functions. As a result, buildings are often zoned both functionally and mechanically into a number of related areas. Occasionally, the temperature, humidity, and air movement requirements of these zones must be isolated or separated. Sometimes, there is a contrast in the environments of two adjacent areas because one is shut off momentarily or temporarily. Under varying conditions, there may well be need for energy conservation measures to control air leakage or heat flow through inadequate barriers.

AIR LEAKAGE

Air leakage is probably the most serious of these two types of heat gain and loss — and probably the hardest to treat. Besides the leaks around door cracks and electrical and utility boxes in walls, there are ceiling penetrations, including recessed lights and air conditioning grills, which need appropriate seals in certain situations.

Acoustical tile lay-in ceilings are used in many types of public spaces in buildings, including corridors within mechanically zoned areas. These ceilings are not airtight and, furthermore, are often used to create plenum spaces for return air systems with open grilles for airflow. They may allow considerable heat gains through internal structure openings. Such openings may be above walls that stop short of the structure above them; or they may be uncaulked penetrations of walls, slabs, shafts, chases, and so forth, for pipes, ducts, conduit, and special function services.

By its very nature, the construction of a building must accommodate many mechanical systems and services, and plenums, shafts, and pipe chases must be used. Many types of wall penetrations and openings that cannot be seen above ceilings do occur.

The mechanical systems engineer for the building may be the first to suspect energy losses through hidden paths of internal leakage: they may even be causing imbalances in the building's systems. Leakage should be investigated by the systems engineer and maintenance personnel (both on a suspicion basis during the basic energy audit of the building) and treatment should be performed according to what is found.

CONDUCTIVE HEAT FLOW

Conductive heat flow through walls, floors, ceilings, and internal barriers, will be of concern only when an area is much hotter or much colder than the adjacent occupied space. Such conditions should be anticipated by the building staff, especially the mechanical systems engineer and those responsible for the energy management program for the facility. They should be able to plan accordingly by considering the installation of additional insulation treatment, as well as control of air leakage.

CONCLUSIONS

While many small efforts can be made for energy conservation in the existing building envelope, some of the more complicated measures are both expensive and disruptive. However, treatment should not be viewed with dismay. Some of the expensive, disruptive opportunities for energy conservation can be carried out in any expansion remodeling. In addition, the experience of energy audits and total energy management can make a major impact on the planning of future facilities.

EXERCISES

1. What are the major areas of air infiltration and exfiltration in a typical building?
2. Given identical buildings in different geographical locations, what would be the most important factor in determining which building energy system would benefit more from a reduction of air infiltration/exfiltration?
3. There are many ways to control solar heat gain, including reflective polyester films that are applied to the inside of window panes. What is the primary factor to consider before applying these relatively permanent films?
4. Given a choice between window units of 1.1 U value and 0.65 U value, which should be installed? Why?
5. Heating degree days (HDD) and cooling degree days (CDD) measure the severity of the entire season. Which climatic zone(s) has the most severe winter? Which zone(s) has the most severe summer? Which season varies the least across all climatic zones? (See Figure 1.)
6. Compute the U value for a wall of this description:

Construction	Resistance (R)
Outside surface (15 mph wind)	0.17
Face brick (6 in)	0.66
Cement mortar (1 in)	0.20
Concrete block (stone agg) (4 in)	0.71
Air space	0.85
Gypsum wallboard (1/2 in)	0.50
Inside surface (still air)	0.68

7. What is the R value of a roof with a U value of 0.30?

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McClure, Charles J.R. "Optimizing Building Energy Use," ASHRAE Journal, September 1971.

TEST

In the blanks beside each of the following questions, enter true or false.

1. Environmental zones are determined by the severity of an entire season. ______
2. When a window's exterior air film is destroyed by wind, its U value decreases. ______
3. Mean radiant temperature can be improved by providing internal window coverings. ______
4. A roof with a total thermal resistance of 6.23 has a U value of 0.145. ______
5. Radiation is the first priority in determining how to reduce heat gain through windows. ______
6. Exterior shading is most effective when added to western and southern exposures. ______
7. Heating degree days for an area with a mean daily temperature of 62°F would be 0.33 degree days. ______
8. If the difference between the temperature of air inside a duct and the temperature of the unconditioned air in the attic space is 23°F, there should be roughly 1.5 inches of duct insulation. ______
9. Reflective polyester films should be applied to the outer surface of the inner glazing of double glazed windows. ______

10. Match the terms in Column A with the appropriate energy conservation opportunity (ECO) in Column B. Place the letter of the answer beside the corresponding term. (Each term may apply to more than one ECO.)

Column A

_____ Wind pressure
_____ Orientation
_____ Fixed systems
_____ Environmental zones
_____ R value
_____ Stack effect
_____ Unconditioned space
_____ Heating degree days
_____ U value
_____ Double glazing
_____ Closed cell foam
_____ Air leakage

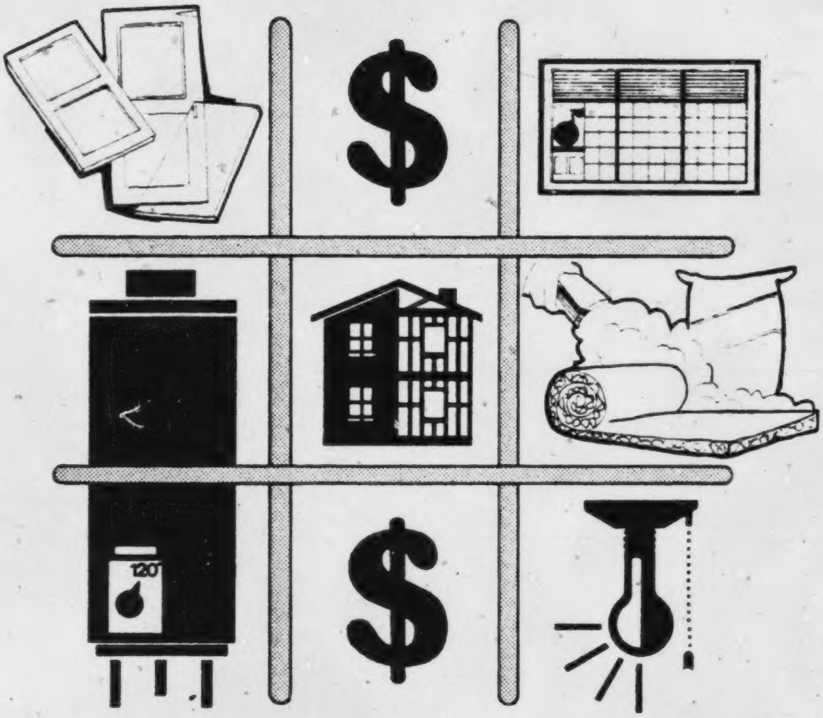
Column B

a. Reduction of infiltration and exfiltration
b. Reduction of solar heat gain through windows
c. Reduction of heat loss through windows
d. Reduction of heat gain and loss through walls, roof, floors, and slabs
e. Reduction of internal heat transfer

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY AUDITS



MODULE EA-05

LIGHTING SYSTEMS

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

Module EA-05, "Lighting Systems," analyzes lighting in terms of (1) the distinct lighting system and (2) the lighting system as it interrelates with other energy use systems of a building. The lighting system discussion covers lamp efficiency, guidelines for efficiency in fixture replacement and system modification, and information on color rendering. Discussion of the lighting system's impact on other energy use systems includes material on usage pattern modifications, recommended illumination standards, and nonuniform – or task – illumination. The latter portion of this module summarizes opportunities for conserving energy in lighting systems. Sample lighting systems' energy savings calculations are included in the exercises.

PREREQUISITES

The student should have completed Module EA-04, "Building Systems."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Discuss usage pattern modifications and methods for determining their applicability to particular buildings.
3. List major lamp types and rank them in terms of lumens per watt.
4. Explain the impact of nonuniform illumination on the building energy system.

4. Define the Color Rendering Index and explain its use in energy-efficient lighting system modification/design.
5. Calculate lighting energy use and costs and determine potential cost savings for various lighting systems and modifications.

LIGHTING SYSTEMS: MODIFICATIONS AND REQUIREMENTS

Because the lighting systems of many existing buildings were designed within the restrictions of initial cost economies – without knowledge about final space use and subdivision, and without benefit of relatively recent developments and research findings in the field – there is a significant potential for lighting system modification.

These modifications can reduce substantially the energy consumed by the lighting system (and associated costs) and, at the same time, provide occupants with the quality and quantity of illumination required to perform various tasks and functions.

Before undertaking any change, one must recognize that a lighting system is just that – a system. Its elements are interrelated, just as the lighting system itself is interrelated with other systems in the building. While energy can be conserved by properly removing lamps and luminaries, action should be taken only after the entire system has been analyzed and all options evaluated.

Although conservation of energy is important, it must be achieved in a manner consistent with other requirements. Other requirements include productivity and visual comfort; aesthetics; federal, state, and local codes and ordinances, and so forth.

Moreover, it is important to recognize that major alterations to a lighting system can have a significant impact on heating and cooling systems; these systems consider the amount of heat given off by the lighting system as originally designed. For these reasons, it is mandatory that competent technical assistance be obtained before significant modifications are undertaken. Modifications should be made only after (1) analyzing the building's illumination needs; (2) compiling information about the lighting system that currently exists; and (3) considering the many options that can be utilized.

The following material discusses the components of lighting systems and highlights many of the actions that can be taken to implement an effective program of lighting energy management.

LAMP TYPES

There are three general types of electric light sources: (1) incandescent lamps, (2) fluorescent lamps, and (3) high-intensity discharge lamps. These are shown in Figures 1-4. Table 1 ranks lamp types by amount of light (lumens) per unit of energy (watt).

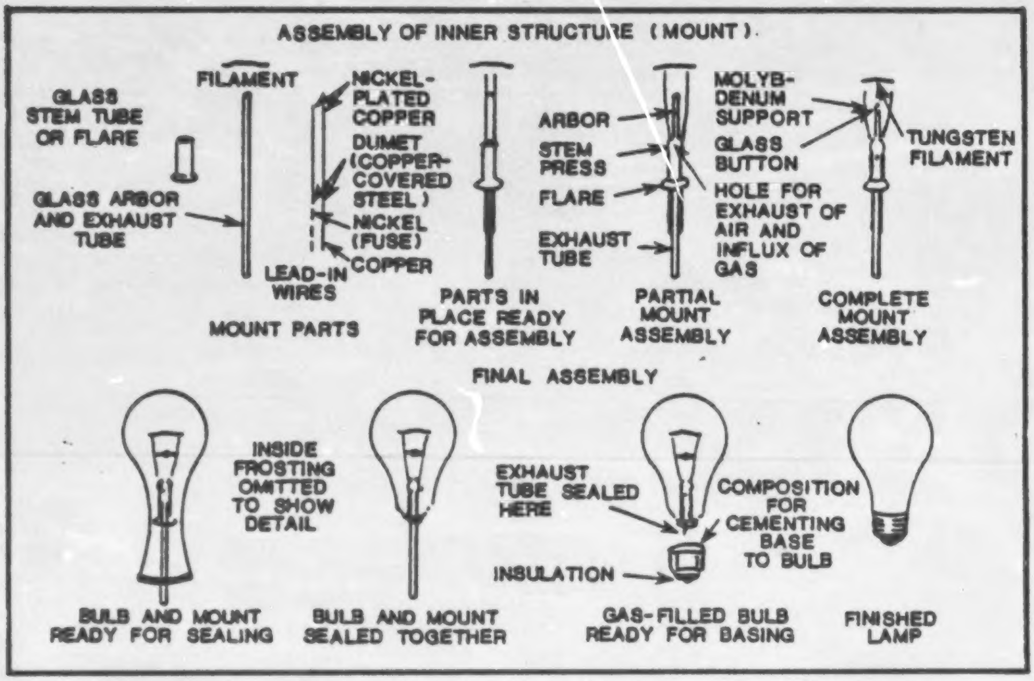
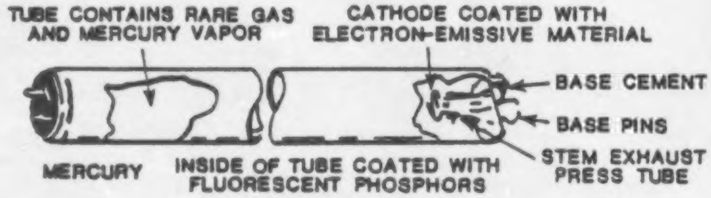
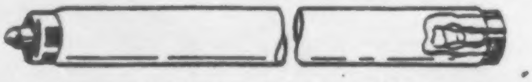

ASSEMBLY OF INNER STRUCTURE (MOUNT)
GLASS STEM TUBE OR FLARE
FILAMENT
NICKEL-PLATED COPPER
DUMET (COPPER-COVERED STEEL)
NICKEL (FUSE)
COPPER
GLASS ARBOR AND EXHAUST TUBE
LEAD-IN WIRES
MOUNT PARTS
PARTS IN PLACE READY FOR ASSEMBLY
ARBOR
STEM PRESS
FLARE
EXHAUST TUBE
MOLYBDENUM SUPPORT
GLASS BUTTON
HOLE FOR EXHAUST OF AIR AND INFLUX OF GAS
TUNGSTEN FILAMENT
PARTIAL MOUNT ASSEMBLY
COMPLETE MOUNT ASSEMBLY
FINAL ASSEMBLY
INSIDE FROSTING OMITTED TO SHOW DETAIL
EXHAUST TUBE SEALED HERE
COMPOSITION FOR CEMENTING BASE TO BULB
INSULATION
BULB AND MOUNT READY FOR SEALING
BULB AND MOUNT SEALED TOGETHER
GAS-FILLED BULB READY FOR BASING
FINISHED LAMP

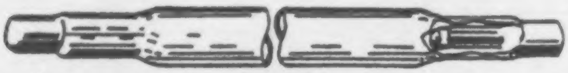
Figure 1. Steps in the Manufacture of a Typical Incandescent Filament Lamp.


TUBE CONTAINS RARE GAS AND MERCURY VAPOR
CATHODE COATED WITH ELECTRON-EMISSIVE MATERIAL
BASE CEMENT
BASE PINS
STEM PRESS
EXHAUST TUBE
MERCURY
INSIDE OF TUBE COATED WITH FLUORESCENT PHOSPHORS

a. Hot-Cathode (Filamentary) Preheat-Starting



b. Hot-Cathode (Filamentary) Instant-Starting



c. Cold-Cathode (Cylindrical) Instant-Starting

Figure 2. Cutaway View of Fluoresent Lamps Showing Typical Electrodes.

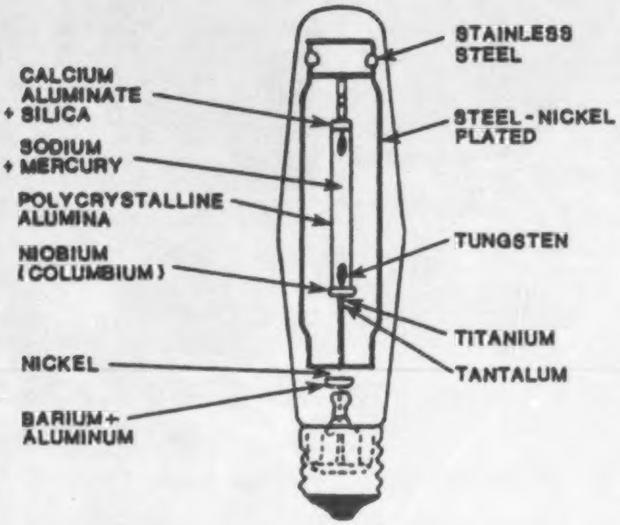

STAINLESS STEEL
CALCIUM ALUMINATE + SILICA
STEEL-NICKEL PLATED
SODIUM + MERCURY
POLYCRYSTALLINE ALUMINA
TUNGSTEN
NIOBIUM (COLUMBIUM)
TITANIUM
NICKEL
TANTALUM
BARIUM + ALUMINUM

Figure 3. Construction of a Typical High-Pressure Sodium Lamp.

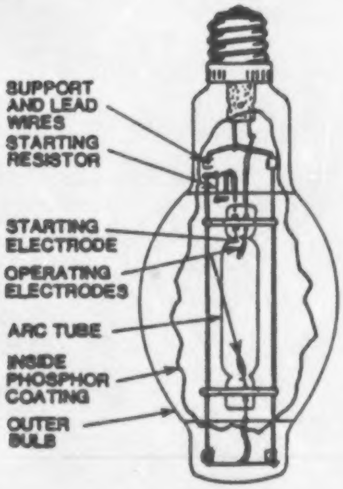

SUPPORT AND LEAD WIRES
STARTING RESISTOR
STARTING ELECTRODE
OPERATING ELECTRODES
ARC TUBE
INSIDE PHOSPHOR COATING
OUTER BULB

Figure 4. A 400-Watt Phosphor-Coated Mercury Lamp. Lamps of Other Sizes are Constructed Similarly.

TABLE 1. LUMENS PER WATT FOR DIFFERENT LAMP TYPES (Including Ballast).*

Type	Smaller Sizes	Middle Sizes	Larger Sizes
High-pressure sodium	84	105	126
Metal halide	67	75	93
Fluorescent	66	70	74
Mercury	44	51	57
Incandescent	17	22	24

*Ballasts add at least 15-20T to the rated energy usage of bulbs.

This ranking, of course, is only general. There is overlapping of efficiencies between lamp types – and even within a lamp type – of different wattages, life ratings, and so forth. Also, there are limitations on the suitability of some lamps for a specific application.

Selection of the most efficient lamp must be evaluated on the basis of the specific application and the performance characteristics of the individual lamps being considered. Changing from incandescent to a more efficient light source can give paybacks in as little as one to two years, depending on local energy costs.

INCANDESCENT LAMPS

Incandescent lamps, the most common light sources in general use, are lamps in which light is produced by a filament (usually tungsten) heated to incandescence by an electric current. As a general rule, there is an increase in efficiency with increased incandescent bulb wattage. For example, a typical 60-watt bulb produces 15 lumens per watt; a typical 100-watt bulb produces 18 lumens per watt. Thus, it is frequently possible to replace two bulbs of lower wattage with one of higher wattage and achieve the same light output for less energy consumption.

As the tungsten filament incandesces, molecules of the metal burn off and coat the inside of the bulb, causing darkening. Over the life of the lamp, this darkening can cause a light output depreciation of 20%.

Long-life bulbs are usually the least efficient incandescent lamps. Therefore, long-life bulbs should be used only in applications where lamp changing is inconvenient or dangerous or when lighting requirements are very low.

Three types of incandescent lamps are suited to special applications: reflector lamps (R-lamps), parabolic aluminized reflector (PAR) lamps, and ellipsoidal reflector (ER) lamps.

R-Lamps

R-lamps have an interior aluminum coating to direct light output. They are well-suited for recessed or directional fixtures and task lighting. In these applications, a 50-watt R-lamp puts as much light on the task as would a 100-watt standard bulb.

PAR Lamps

PAR lamps have a heavy lens and an aluminized reflector. PAR lamps are suitable for outdoor applications and have a longer life and lower lighting output depreciation than standard bulbs.

ER Lamps

ER lamps have lenses that focus the light beam two inches ahead of the lamp. For this reason, ER lamps are well-suited to applications in recessed fixtures.

FLUORESCENT LAMPS

Unlike incandescent lamps, fluorescent lamps do not depend on heat for light production. Rather, fluorescent lamps are low-pressure mercury, electric-discharge lamps in which a fluorescing coating (phosphor) transforms some of the ultraviolet energy generated by the discharge into light. Fluorescent lamps are inherently more efficient (more lumens per watt) than incandescent lamps, and, as a general rule, fluorescent lamp efficiency increases as the length of the tube increases.

HIGH INTENSITY DISCHARGE (HID) LAMPS

Light is produced in HID lamps by the passage of electric current through a vapor or a gas. HID lamps are the most efficient electric light sources and are well-suited to the high wattage requirements and long hours of outdoor applications. There are drawbacks to HID lamps, however; they have poor color rendition and there is a startup delay of one to seven minutes. To compare the performance of discharge lamps, see Table 2. Table 3, "Color Rendering Index (CRI)," compares specific light sources to natural light. The higher the CRI, the more closely the light source simulates natural light.

TABLE 2. COMPARISON OF TYPICAL DISCHARGE LAMP PERFORMANCE.

Lamp Type	Initial			End of Life*		
	Lumens	Lumens Per Watt		Lumens	Lumens Per Watt	Rated Average Life**
		Lamp	Lamp/Ballast			
Low-Pressure Sodium 180 W	33,000	180	150	33,000	117	18,000
High-Pressure Sodium 400 W	50,000	125	106	35,000	76	24,000
Super Metalarc 400 W	40,000	100	88	27,200	60	15,000
Metalarc (Metal Halide) 400 W	34,000	85	75	22,500	50	20,000
Mercury 400 W	23,000	57	51	15,700	35	24,000
Fluorescent VHO 2/215 W	32,000	74	71	21,760	48	15,000

* Includes ballast losses.
** Operated on 10-hour burning cycle.

Source: Sylvania

TABLE 3. COLOR RENDERING INDEX (CRI).

Lamp Type	CRI
Natural Light	100
Incandescent	97
Fluorescent	
Cool White	67
Deluxe Cool White	86-89
Warm White	56
Warm White Deluxe	71
Daylite	75
Vita-Lite	91
Ultralume	85
Energy Efficient	
Lite-White	48
Econo-O-White	51
Mercury	22-52
Metal Halide	65-70
High-Pressure Sodium	20
Low-Pressure Sodium	0

There are three common types of HID lamps: mercury, metal halide, and high-pressure sodium.

Mercury Lamps

Mercury lamps are the most common HID lamps. They have a long life and comparatively low installation cost, and they produce twice as much light per watt as incandescent lamps. While the clear mercury lamps give poor color rendition (blue is accentuated), color-corrected mercury lamps are available.

Metal Halide Lamps

Metal halide lamps are more efficient than mercury lamps and give better color rendition. Since the lowest wattage available in metal halide lamps is 175, they are not commonly used in residential applications.

Sodium Lamps

Next to low-pressure sodium lamps (which are not widely used because of their poor color-rendering characteristics), high-pressure sodium lamps are the most energy-efficient electric light sources. The lowest wattage available in high-pressure sodium lamps is 70, which is too bright for interior residential application. Their light is a gold-white that dulls the color of reds and blues.

ENERGY CONSERVATION OPPORTUNITIES

Energy conservation opportunities include usage pattern modifications, work station modifications, maintenance considerations, illumination level modifications, control modifications, and heat-of-light recovery systems.

USAGE PATTERN MODIFICATIONS

An excellent initial step for a program of lighting management is to modify usage patterns based on factors identified during the building energy audit. Changes made to the building system often mean that lighting usage patterns must be changed to correspond to modifications; but, for the most part, modifications are relatively simple once initial steps have been undertaken.

An effective lighting usage program depends on a planned program to turn lights ON when and where they are needed. The major advantages of such a program are that (1) lighting can be tailored to the individual characteristics of the space and needs of its occupants, and (2) such programs can be implemented relatively inexpensively and quickly. The key element of a lighting usage program is a lighting schedule related to the occupants' usage pattern. Personnel should be assigned, trained, and made responsible for the efficient utilization of lighting by means of established schedules to control lighting.

Program Considerations

The exact nature of occupancy for each period of time should be defined. Then, the amount of lighting needed for safety and security purposes must be determined. Based on this information, detailed instructions and training for system operation should be provided to appropriate employees. Information can be communicated by charts, posting of instructions, and/or color-coding switches. Training should assure that the employees who control lighting use understand proper procedures so that they can comply with them.

Program Options

The following options should be considered part of the overall program:

- Campaign for better utilization by using letters, memos, signs, and personal contact to encourage occupants – especially custodial personnel – to use lighting only when it is needed, to use only the amount of lighting required, and to turn OFF lights whenever they are not being used.
- Post small signs or charts near each panel to identify which lighting is controlled by the switches or circuit breakers involved. This enables the user to be more selective while also reducing trial and error, which can consume significant amounts of energy when banks of lights are quickly activated and deactivated.

WORK STATION MODIFICATIONS

Work stations can be relocated to take maximum advantage of the lighting system that exists, or to supplement or effect changes to other elements of the system. Typical modifications to work station locations are as follows:

- Desks and other work surfaces should be moved to a position and orientation that will use installed luminaries to their greatest advantage (instead of moving luminaries).
- To the extent permitted by productivity requirements and related concerns, tasks that require approximately the same levels of illumination should be grouped together. This may reduce the number of areas requiring higher illumination levels and provide an opportunity to reduce the total amount of lighting needed.
- Work stations requiring the highest illumination levels should be located nearest the windows. (Note: Utilization of natural light will have an impact on heat gain, requiring that the heat gain/light gain trade-off be given careful consideration. In many cases, glazing can be modified to limit heat gain, while still permitting entry of a significant amount of light.) To reduce glare, rearrange work surfaces so that sidewall daylighting crosses the task perpendicular to the line of vision.

MAINTENANCE CONSIDERATIONS

Proper maintenance of lighting system components serves to keep the system running at peak efficiency. This not only conserves energy and energy costs, but also helps maintain quality illumination and extends lamp and luminaire life. The following maintenance considerations should be reviewed.

- Lamp efficiency deteriorates over the life of a lamp. Auditors and/or maintenance personnel should check light output regularly with a calibrated light meter. When the light output of a group of lamps has fallen to approximately 70% of the original light output, all fixtures in the group should be relamped at the same time. This is also a good time to determine whether a more efficient or lower-wattage lamp is suitable.

- Lamps should be wiped clean at regular intervals to assure maximum efficiency. Lamps that are exposed to an atmosphere with substantial amounts of dirt, grease, or other contaminants should be cleaned more frequently than lamps in a relatively clean atmosphere.

- Luminaire efficiency can be maintained by properly cleaning the reflecting surfaces and shielding media. Lens shielding that has yellowed or weakened should be replaced with a clear acrylic lens that has good nonyellowing properties. For some applications, a clear glass lens can be considered if it is compatible with the luminaire and does not present a safety hazard. (Caution should be taken to assure that an existing luminaire will safely support and hold the glass lens.)

- Ceilings, walls, and floors should be cleaned frequently to improve their reflective qualities. When daylight is used, windows should be washed frequently to maintain illumination levels on tasks that require some natural illumination.

- Light reflective, non-glossy colors on walls and ceilings will make more efficient use of existing illumination and make work areas seem lighter to occupants.

ILLUMINATION LEVEL MODIFICATIONS

While it is commonly understood that different visual tasks require different levels of illumination, the interiors of many buildings provide only uniform illumination levels. These uniform levels have little relationship to the amount of illumination required in specific areas.

There are usually several levels of illumination required within any building. These levels can be separated into three general categories: specific task lighting, general lighting around tasks, and general lighting for circulation or support areas.

During a building's original design, the lighting designer frequently cannot define the nature or location of specific tasks or task areas. The designer's problem is often compounded by lack of knowledge about final partition locations, floor, and wall finishes – all of which have an impact on the final illumination results.

After a building or space is completely defined or occupied, there are usually opportunities to adjust illumination levels to improve utilization and efficiency. If the wiring and lighting system is flexible enough to allow for relocating luminaires, then individual lamps or groups of lamps can be switched together to control light in specifically defined areas; such adjustments can be made quickly and inexpensively. In buildings without such flexibility, it may be necessary to add switching, remove lamps, or disconnect or add lighting systems in order to provide proper illumination for individual tasks and still accomplish the desired energy reduction.

In general administrative areas, nonuniform lighting systems can be applied when the average work station size is less than one worker per 50-70 square feet. If work stations are larger, a uniform lighting system is generally more practical. Nonuniform lighting applications can also save energy in large private office areas. Since usage usually changes several times over the life of a building, special consideration should be given to providing flexibility in the lighting and control systems. The energy auditor should be able to recommend lighting system modifications on the basis of information supplied in illumination standards (see Appendix).

Reducing Lighting Levels

Of various illumination level standards, one published by the U.S. Department of Energy, in "Lighting and Thermal Operations Guidelines," is considered the most appropriate for office work (see Table 4). The principal feature of the standard is the promotion of nonuniform illumination. Only the task has full illumination and the lighting in the surrounding areas can and should be reduced. Tasks that are somewhat more difficult visually, but of short duration, can usually be handled at the lower footcandle level. This is accomplished by moving the eyes and task closer together, rather than by increasing the illumination level.

In addition, one required program measure in all state energy conservation plans is a thermal and lighting standard for new buildings. These standards prescribe lighting levels by building type (e.g., retail, health care, and local government). These standards are frequently calculated in watts per square foot for the entire building.

TABLE 4. RECOMMENDED MAXIMUM LIGHTING LEVELS.

Task or Area	Footcandle Levels	How Measured
Hallways or corridors	10 ± 5	Measured average, minimum 1 footcandle.
Work and circulation areas surrounding work stations	30 ± 5	Measured average.
Normal office work, such as reading and writing (on task only), store shelves, and general display areas	50 ± 10	Measured at work station.
Prolonged office work that is somewhat difficult visually (on task only)	75 ± 15	Measured at work station.
Prolonged office work that is visually difficult and critical in nature (on task only)	100 ± 20	Measured at work station.

Lamp Modifications

Lamp modification can take many forms. Modifications can involve elimination of lamps, using lamps of lower wattage, and changing the type of lamp involved (which would imply, in most cases, a change of luminaire). The energy auditor should consider the following:

- Unnecessary lamps should be removed, if removal will still provide required illumination levels. When lamps are removed from a fluorescent luminaire, all lamps controlled by a given ballast should be disconnected; otherwise, ballast failure or reduced lamp light will result. Except in the case of instant-start lamps or luminaires with circuit-interrupting lampholders, ballasts should also be disconnected; otherwise, they will continue to consume energy.
- Consideration should be given to replacing present lamps with those of lower wattage that provide the same amount of illumination or a lower level of illumination (if acceptable in light of tasks involved).

(Changing the lens or lowering the luminaire often can help facilitate this option.) This method is particularly applicable where current lighting levels are higher than recommended, or where uniform lighting is most practical due to occupant density. This is also a simple way to provide flexibility should higher levels of illumination be required at some future time. (Note: New lamps must be compatible for use with existing ballasts in fluorescent and HID luminaires.)

- Generally, lamps should be selected that are the most efficient (produce the most lumens per watt) and are compatible with the application. Compatibility with the luminaire, of course, also is essential. If some luminaire replacement is to be undertaken, the type of lamp involved also should be considered. (Table 1 showed the efficiencies of various lamp types.)

- Where possible, a single, larger incandescent lamp should be used rather than two or more smaller lamps. Higher-wattage, general service incandescent lamps are more efficient than lower-wattage lamps.

- Multi-head lamps should be avoided. The efficiency of a single-wattage lamp is higher per watt than a multi-level lamp.

- Extended service lamps should be used, except in special cases like recessed directional lights, where short lamp life is a problem.

- When relamping, the replacement of 40-watt fluorescent lamps with 35-watt lamps will achieve a reduction in lighting level of approximately 18%, and save 20% in fixture electrical energy.

- When retrofitting, the use of higher power factor ballasts should be considered. High-efficiency ballasts consume only half the energy of conventional fluorescent ballasts and, thus, dissipate less heat into the environment and have a longer useful life.

Luminaire Modifications

Luminaire efficiency is measured by the coefficient of utilization. While efficiency is an important consideration in luminaire selection, one also must consider visual comfort. The following guidelines are provided for the three general types of applications:

- For tasks where veiling reflections are a critical factor and visual comfort is important, the luminaire can have a coefficient of utilization of 0.55 or higher. It also should have high visual comfort.
- For spaces where veiling reflections are not a critical factor, but where visual comfort is still a factor, the luminaire can have a coefficient of utilization of 0.63 or higher, and medium to high visual comfort.
- For spaces that do not involve critical visual tasks, and where visual comfort is not a factor, the luminaire can have a coefficient of utilization of 0.70 or higher and low visual comfort.

More specific information regarding coefficients of utilization and visual comfort can be obtained from the Illuminating Engineering Society Lighting Handbook and from manufacturers' data for specific luminaires.

Some possible modifications to luminaires include the following:

- If existing lighting causes veiling reflections and it is impractical to relocate a work station, luminaires can be relocated to provide light at an angle to the task.
- Outdated or damaged luminaires should be replaced with modern luminaires that are easily cleaned, easily maintained, and that use lamps with higher efficiencies.

- In multiple-purpose spaces that require more than one level of illumination, the installation of fluorescent luminaires with multiple-level ballasts – or the addition of solid-state dimming controls for incandescent luminaires – can reduce the amount of energy necessary for lighting.
- Luminaires can be lowered. This will provide recommended illumination levels on the task area at reduced wattage.
- Where appropriate, lenses should be installed to provide special light distribution patterns to increase lighting effectiveness. For example, linear batwing, radial batwing, parabolic louvers, or polarizing lenses may provide better visibility with the same (or even reduced) wattage. It is suggested that competent technical advice be obtained to evaluate where such lenses can be used most effectively.
- All incandescent parking lights can be replaced with high-pressure sodium, mercury-vapor HID lamps.

CONTROL MODIFICATIONS

In many cases, modification of existing lighting controls, and addition of new lighting controls, can have a considerable effect on energy consumption. The following guidelines should be considered by the energy auditor:

- When existing circuitry makes it impossible to utilize less than 25% of the light in a given large space, and when persons work during normally unoccupied periods, a desk lamp issuance program may be developed. This enables persons working during unoccupied periods to use a simple desk lamp (or two) instead of a large bank of luminaires.

- When natural light is available in a building, photocell switching can be used to turn OFF banks of lighting in areas where natural light is sufficient for the task.

- Photocell and/or time clock controls can be used for outdoor lighting that is required for only a part of the period of darkness. Except when needed for safety or security, such lighting should be turned OFF automatically during the late evening or early morning hours.

- Time controls should be installed in those areas of a building that are used infrequently and only for brief periods. These controls turn OFF lights automatically after a set period of time.

- Alternate switching or dimmer controls can be employed when spaces are used for multiple purposes and require different amounts of illumination for the various activities. It is possible to provide multiple levels by providing switching for alternate fixtures, and so forth. Dimmer controls can be effective when it is impractical to use selective switching to obtain multiple lighting levels. This is especially true (and relatively low in cost) when incandescent lighting is involved.

- Selective switching should be used where possible. Initial cost economics and lack of knowledge about final space subdivision often lead to the use of central panelboards as the only means of controlling large blocks of lighting. This design approach precludes the potential for turning ON only the amount of lighting that is needed after the space has been subdivided.

- There are many ways to provide local control of lighting. Local switches can be provided near doorways. Remote-controlled switches can be located near panelboards to control groups of lights. Low-voltage control circuits can be used to provide accessible control of switches located in remote locations. (These controls are usually relatively inexpensive.) When properly used, localized switching usually will save enough energy to provide a payback on the investment within a short period of time.

- Lighting use in remote areas can be monitored by neon indicator lights at central stations. Such lights alert personnel to investigate and turn OFF lights not being used.

HEAT-OF-LIGHT RECOVERY SYSTEMS

Heat-of-light recovery systems – because of the expense they entail – usually are feasible only if they are part of a modernization program. While many different types of heat-of-light recovery systems are available, most provide the same basic functions.

In essence, the heat produced by lighting is extracted by mechanical equipment through a ceiling cavity to the mechanical equipment room. The heat collected can be recycled to reduce heating energy needs in cold weather or discarded to reduce the cooling energy needs during warmer weather. Removal of heat in this manner usually enables luminaires and lamps to operate more efficiently, and also may reduce fan horsepower requirements of the air circulation system.

Figures 5 and 6 show two typical heat-of-light recovery systems. All return air moves through the luminaires in the total return system (Figure 5). Only part of the return air moves through the luminaires in a bleed-off system (Figure 6).

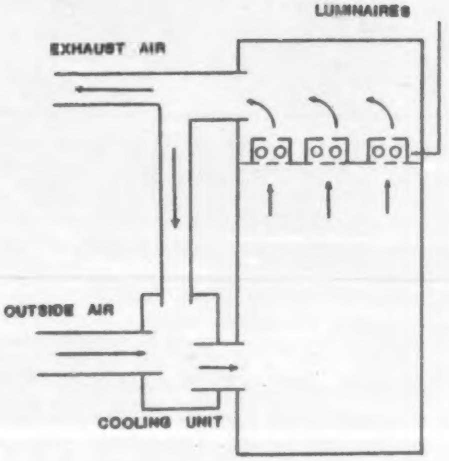

LUMINAIRES
EXHAUST AIR
OUTSIDE AIR
COOLING UNIT

Figure 5. Heat-of-Light Recovery Systems/Total Return System.

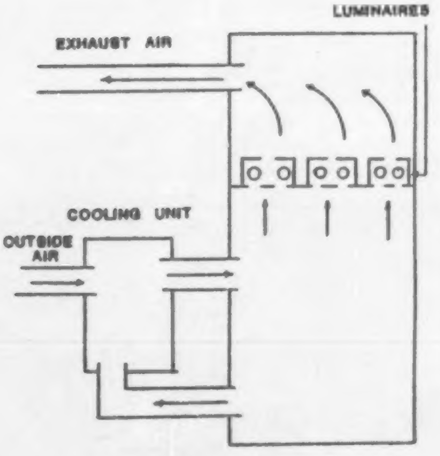

LUMINAIRES
EXHAUST AIR
COOLING UNIT
OUTSIDE AIR

Figure 6. Heat-of-Light Recovery Systems/Bleed-Off System.

SUMMARY

While no two lighting systems have the same potential for energy efficiency improvement, there are standard procedures for analyzing and improving the performance of any system. The no/low cost actions shown in Table 5 can be taken with any lighting system. Retrofit actions (also shown in Table 5) should be undertaken only on the recommendation of a qualified energy auditor and/or lighting engineer, since the effectiveness and economic feasibility of retrofitting can vary from one application to another.

TABLE 5. LIGHTING SYSTEM CONSERVATION OPPORTUNITIES.

NO/LOW COST

Survey with Light Meter.
  -Remove Bulbs, Tubes, and Ballasts.
  -Start Using Energy-Efficient Bulbs and Tubes.
Clean Bulbs and Tubes.
Clean Fixtures.
Set Manual Lighting Schedule.

RETROFIT

Remove Fixtures.
Rewire Switches.
Retrofit with Energy-Efficient Ballasts and Tubes.
Replace Mercury with Metal Halide, High-Pressure Sodium or Low-Pressure Sodium.
Use Photocells.
Use Timers.

EXERCISES

1. List five lighting system maintenance considerations that can conserve energy and maintain high-quality illumination.
2. The lighting level measured at a work station where prolonged, visually difficult office work is done is 65 footcandles. Are any modifications necessary? If so, what are they? What would be accomplished?
3. The measured average light level in a corridor is 30 footcandles. Are any modifications necessary? If so, what are they? What would be accomplished?
4. Given a task where veiling reflection and visual comfort are both important, and a choice of light sources with coefficients of utilization of 0.45, 0.78, and 0.90, which is the best choice? Why?
5. In an application that permits the use of fluorescent lamps, but demands good color rendition, what would be the best three light choices, in order of preference? How does each choice compare with natural light?
6. What modifications should be made to an accounting office lighting system that uses tungsten filament incandescent lamps to produce an illumination level of 200 footcandles on task areas?
7. One energy-conserving operation and maintenance action that can be taken with lighting systems is to disconnect unnecessary fluorescent lamp tubes and ballasts. Use the following information to calculate total energy saved during the cooling season:
    a. Fluorescent ballasts consume approximately 15% of the rated power requirement of the tubes removed from the fixture (luminaire).

b. For every 1000 watts of lighting energy saved, an additional 300 watts of cooling energy is saved in Texas (for example).

c. In this example, assume that the total wattage of tubes removed = 5500 watts.

d. Assume also that the lights are used for 945 hours in the cooling season.

e. 1000 watts = 1 kilowatt.

Energy Saving Calculation:

a x b x c x d ÷ e = __________ kWh/season

(NOTE: During the heating season, for every Btu of lighting energy saved, a Btu of heating [output] energy will be provided from some other source – e.g. furnace, boiler, heat pump, and so forth.)

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APPENDIX

RECOMMENDED ILLUMINATION LEVELS ON TASK

Area	Footcandles on tasks*
Aircraft manufacturing	
Stock parts	
Production	100
Inspection	200
Parts manufacturing	
Drilling, riveting, screw fastening	70
Spray booths	100
Sheet aluminum layout and template work, shaping, and smoothing of small parts for fuselage, wing sections, cowling, etc.	100
Welding	
General illumination	50
Precision manual arc welding	1000
Subassembly	
Landing gear, fuselage, wing sections, cowling, and other large units	100
Final assembly	
Placing of motors, propellers, wing sections, landing gear	100
Inspection of assembled ship and its equipment	100
Machine tool repairs	100
Aircraft hangers	
Repair service only	100
Armories	
Drill	20
Exhibitions	30
Art galleries	
General	30
On paintings (supplementary)	30
On statuary and other displays	100
Assembly	
Rough, easy seeing	30
Rough, difficult seeing	50
Medium	100
Fine	500
Extra fine	1000
Auditoriums	
Assembly only	15
Exhibitions	30
Social activities	5
Automobile manufacturing	
Frame assembly	50
Chasis assembly line	100
Final assembly, inspection line	200
Body manufacturing	
Parts	70
Assembly	100
Finishing and inspecting	200
Bakeries	
Mixing room	50
Face of shelves (vertical illumination)	30
Inside mixing bowl (vertical illumination	50
Fermentation room	30
Make-up room	
Bread	30
Sweet yeast-raised products	50
Proofing room	30
Oven room	30
Fillings and other ingredients	50
Decorating and icing	
Mechanical	50
Hand	100
Scales and thermometers	50
Wrapping room	30
Banks	
Lobby	
General	50
Writing areas	70†
Tellers' stations	150‡
Posting and keypunch	150
Barber shops and beauty parlors	100
Book binding	
Folding, assembling, pasting, etc.	70
Cutting, punching, stitching	70
Embossing and inspection	200
Breweries	
Brewhouse	30
Boiling and keg washing	30
Filling (bottles, cans, kegs)	50
Candy making	
Box department	50
Chocolate department	
Husking, winnowing, fat extraction, crushing and refining, feeding	30
Bean cleaning, sorting, dipping, packing, wrapping	50
Milling	100
Cream making	
Mixing, cooking, molding	50
Gum drops and jellied forms	50
Hand decorating	100
Hard candy	
Mixing, cooking, molding	50
Die cutting and sorting	100
Kiss making and wrapping	100
Canning and preserving	
Initial grading raw material samples	50
Tomatoes	100
Color grading (cutting rooms)	200
Preparation	
Preliminary sorting	
Apricots and peaches	50
Tomatoes	100
Olives	150
Cutting and pitting	100
Final sorting	100
Canning	
Continuous-belt canning	100
Sink canning	100
Hand packing	50
Olives	100
Examination of canned samples	200

*Minimum on the task at any time for young adults with normal and better than 20/30 corrected vision.

Area	Footcandles on tasks*
Container handling	
Inspection	200
Can unscramblers	70
Labeling and cartoning	30
Central station	
Air conditioning equipment, air preheater and fan floor, ash sluicing	10
Auxiliaries, battery rooms, boiler feed pumps, tanks, compressors, guage area	20
Boiler platforms	10
Burner platforms	20
Cable room, circulator, or pump bay	10
Chemical laboratory	50
Coal conveyor, crusher, feeder, scale areas, pulverizer, fan area, transfer tower	10
Condensers, deaerator floor, evaporator floor, heater floors	10
Control rooms (see Control rooms)	
Hydrogen and carbon dioxide manifold area	20
Precipitators	10
Screen house	20
Soot or slag blower platform	10
Steam headers and throttles	10
Switchgear, power	20
Telephone equipment room	20
Tunnels or galleries, piping	10
Turbine bay sub-basement	20
Turbine room	30
Visitor's gallery	20
Water treating area	20
Chemical works	
Hand furnaces, boiling tanks, stationary driers, stationary and gravity crystallizers	30
Mechanical furnaces, generators and stills, mechanical driers, evaporators, filtration, mechanical crystallizers, bleaching	30
Tanks for cooking, extractors, percolators, nitrators, electrolytic cells	30
Churches and synagogues	
Altar, ark, reredos	100
Choir and chancel	30
Classrooms	30
Pulpit, rostrum (supplementary illumination	50
Main worship area	
Light and medium interior finishes	15
For churches with special zeal	30
Art glass windows (test reccomended)	
Light color	50
Medium color	100
Dark color	500
Especially dense windows	1000
Clay products and cements	
Grinding, filter presses, kiln rooms	30
Molding, pressing, cleaning, trimming	30
Enameling	100
Color and glazing, rough work	100
Color and glazing, fine work	300
Cleaning and pressing industry	
Checking and sorting	50
Dry and wet cleaning and steaming	50
Inspection and spotting	500
Pressing	150
Repair and alteration	200
Cloth products	
Cloth inspection	2000
Cutting	300
Sewing	500
Pressing	300
Clothing manufacture (men's)	
Receiving, opening, storing, shipping	30
Examining (perching)	2000
Sponging, decating, winding, measuring	30
Piling up and marking	100
Cutting	300
Pattern making, preparation of trimming, piping, canvas and shoulder pads	50
Fitting, bundling, shading, stitching	30
Shops	100
Inspection	500
Pressing	300
Sewing	500
Club and lodge rooms	
Lounge and reading rooms	30
Auditoriums (see Auditoriums)	
Coal tipples and cleaning plants	
Breaking, screening, and cleaning	10
Picking	300
Control rooms and dispatch rooms	
Control rooms	
Vertical face of switchboards	
Simplex or section of duplex facing operator:	
Type A-Large centralized control room 66 inches above floor	50
Type B-Ordinary control room 66 inches above floor	30
Section of duplex facing away from operator	30
Bench boards (horizontal level)	50
Area inside duplex switchboards	10
Rear of all switchboard panels (vertical)	10
Emergency lighting, all areas	3

*Minimum on the task at any time for young adults with normal and better than 20/30 vision.

Area	Footcandles on tasks*
Dispatch boards	
Horizontal plane (desk level)	50
Vertical face of board 48 inches above floor, facing operator):	
System load dispatch room	50
Secondary dispatch room	30
Cotton gin industry	
Overhead equipment: separators driers, grid cleaners, stick machines, conveyers, feeders, and catwalks	30
Gin stand	50
Control console	50
Lint cleaner	50
Bale press	30
Courtrooms	
Seating area	30
Court activity area	70
Diary farms (see Farms)	
Diary products	
Fluid milk industry	
Boiler room	30
Bottle storage	30
Bottle sorting	50
Bottle washers	
Can washers	30
Cooling equipment	30
Filling: inspection	100
Gauges (on face)	50
Laboratories	100
Meter panels (on face)	50
Pasteurizers	30
Separators	30
Storage refrigerator	30
Tanks, vats	
Light interiors	20
Dark interiors	100
Thermometer (on face)	50
Weighing room	30
Scales	70
Dance halls	5
Depots, terminals, and stations	
Waiting room	30
Ticket offices	
General	100
Ticket rack and counters	100
Rest rooms and smoking room	30
Baggage checking	50
Concourse	10
Platforms	20
Toilets and washrooms	30
Dispatch boards (see Control rooms)	
Drafting rooms (see Offices)	
Electrical equipment manufacturing	
Impregnating	50
Insulating: coil winding	100
Testing	100
Electrical Generating Station (see Central Station)	
Elevators, freight and passenger	20
Engraving (wax)	200
Explosives	
Hand furnaces, boiling, tanks, stationary driers, stationary and gravity crystallizers	30
Mechanical furnace, generators and stills, mechanical driers, evaporators, filtration, mechanical crystallizers	30
Tanks for cooking, extractors, percolators, nitrators	30
Farms-dairy	
Milking operation areas (milking parlor and stall barn)	
General	20
Cow's udder	50
Milk-handling equipment and storage area (milk house or milk room)	
General	20
Washing area	100
Bulk tank interior	100
Loading platform	20
Feeding area (stall barn feed alley, pens, loose housing feed area)	20
Feed storage area: forage	
Haymow	3
Hay inspection area	20
Ladders and stairs	20
Silo	3
Silo room	20
Feed storage area: grain and concentrate	
Grain bin	3
Concentrate storage area	10
Feed processing area	10
Livestock housing area (community, maternity, individual calf pens, and loose housing holding and resting areas)	7
Machine storage area (garage and machine shed)	5
Farm shop area	
Active storage area	10
General shop area (machinery repair, rough sawing)	30
Rough bench and machine work (painting, fine storage, ordinary sheet metal work, welding, medium benchwork)	50
Medium bench and machine work (fine woodworking, drill press, metal lathe, grinder)	100
Miscellaneous areas	
Farm office	70
Rest rooms	30
Pumphouse	20
Farms-poultry (see Poultry industry)	

*Minimum on the task at any time for young adults with normal and better than 20/30 corrected vision.

Area	Footcandles on tasks*
Fire hall (see Municipal buildings)	
Flour mills	
Rolling, sifting, purifying	50
Packing	30
Product control	100
Cleaning, screens, man lifts, aisleways and walkways, bin checking	30
Forge shops	50
Food service facilities	
Dining areas	
Cashier	50
Intimate type	
Light environment	10
Subdued environment	3
For cleaning	20
Leisure-type	
Light environment	30
Subdued environment	15
Quick-service type	
Bright surroundings*	100
Normal surroundings*	50
Food displays-twice the general levels, but not under	50
Kitchen, commercial	
Inspection, checking, preparation, and pricing	70
Entrance foyer	30
Marquee	
Dark surroundings	30
Bright surroundings	50
Foundries	
Annealing (furnaces)	30
Cleaning	30
Core making	
Fine	100
Medium	50
Grinding and chipping	100
Inspection	
Fine	500
Medium	100
Molding	
Medium	100
Large	50
Pouring	50
Sorting	50
Cupola	20
Shakeout	30
Garages-automobile and truck	
Service garages	
Repairs	100
Active traffic areas	20
Parking garages	
Entrance	50
Traffic lanes	10
Storage	5
Gasoline station (see Service station)	

Area	Footcandles on tasks*
Glass works	
Mix and furnace rooms, pressing and lehr, glass-blowing machines	30
Grinding, cutting glass to size, silvering	50
Fine grinding, beveling, polishing	100
Inspection, etching and decorating	200
Glove manufacturing	
Pressing	300
Knitting	100
Sorting	100
Cutting	300
Sewing and inspection	500
Hangers (see Aircraft hangers)	
Hat manufacturing	
Dyeing, stiffening, braiding, cleaning, refining	100
Forming, sizing, pouncing, flanging, finishing, ironing	200
Sewing	500
Homes (see Residences)	
Hospitals	
Anesthetizing and preparation room	30
Autopsy and morgue	
Autopsy room	100
Autopsy table	1000
Museum	50
Morgue, general	20
Central sterile supply	
General, work room	30
Work tables	50
Glove room	50
Syringe room	150
Needle sharpening	150
Storage areas	30
Issuing sterile supplies	50
Corridor	
General in nursing areas: daytime	20
General in nursing areas: night (rest period)	3
Operating, delivery, recovery, and laboratory suites and service areas	30
Cystoscopic room	
General	100
Cystoscopic table	2500
Dental suite	
Operatory, general	70
Instrument cabinet	150
Dental entrance to oral cavity	1000
Prosthetic laboratory bench	100
Recovery room, general	5
Recovery room, local for observation	70

*Minimum on the task at any time for young adults with normal and better than 20/30 corrected vision.

Area	Footcandles on tasks*
(EEG) encephalographic suite	
Office (see Offices)	
Work room, general	30
Work room, desk or table	100
Examining room	30
Preparation rooms, general	30
Preparation rooms, local	50
Storage, records, charts	30
Electromyographic suite	
Same as EEG, but provisions for reducing level in preparation area to 1	
Emergency operating room	
General	100
Local	2000
ERG, BMR, and specimen room	
General	30
Specimen table	50
EKG machine	50
Examination and treatment room	
General	50
Examining table	100
Exits, at floor	5
Eye, ear, nose, and throat suite	
Darkroom (variable)	0-10
Eye examination and treatment	50
Ear, nose, throat room	50
Flower room	10
Formula room	
Bottle washing	30
Preparation and filling	50
Fracture room	
General	50
Fracture table	200
Splint closet	50
Plaster sink	50
Intensive care nursing areas	
General	30
Local	100
Laboratories	
General	50
Close work areas	100
Linens (see Laundries)	
Sorting soiled linen	30
Central (clean) linen room	30
Sewing room, general	30
Sewing room, work area	100
Linen closet	10
Lobby (or entrance foyer)	
During day	50
During night	20
Locker rooms	20
Medical records room	100
Nurses station	
General: day	70
General: night	30
Desk for records and charting	70
Table for doctor's making or viewing reports	70
Medicine counter	100
Nurses gown room	
General	30
Mirror for grooming	50
Nurseries, infant	
General	30
Examining, local at basinet	100
Examining and treatment table	100
Nurses station and work space (see Nurses Station)	
Obstetrical suite	
Labor room, general	20
Labor room, local	100
Scrub-up area	30
Delivery room, general	100
Substerilizing room	30
Delivery table	2500
Clean-up room	30
Recovery room, general	30
Recovery room, local	100
Patients' rooms (private and wards)	
General	20
Reading	30
Observation (by nurse)	2
Night light, maximum at floor (variable)	0.5
Examining light	100
Toilets	30
Pediatric nursing unit	
General, crib room	20
General, bedroom	10
Reading	30
Playroom	30
Treatment room, general	50
Treatment room, local	100
Pharmacy	
Compounding and dispensing	100
Manufacturing	50
Parenteral solution room	50
Active storage	30
Alcohol vault	10
Radioisotope facilities	
Radiochemical laboratory, general	30
Uptake or scanning room	20
Examining table	50
Retiring room	
General	10
Local for reading	30
Solarium	
General	20
Local for reading	30
Stairways	20
Surgical suite	
Instrument and sterile supply room	30
Clean-up room, instrument	100
Scrub-up area (variable)	200
Operating room, general (variable)	200
Operating table	2500
Recovery room, general	30
Recovery room, local	100
Anesthesia storage	20
Substerilizing room	30
Therapy, physical	
General	20
Exercise room	30
Treatment cubicles, local	30
Whirlpool	20
Lip reading	150
Office (see Offices)	

*Minimum on the task at any time for young adults with normal and better than 20/30 corrected vision.

Area	Footcandles on tasks*
Therapy, occupational	
Work area, general	30
Work tables or benches, ordinary	50
Work tables or benches, fine work	100
Toilets	30
Utility room	
General	20
Work counter	50
Waiting rooms, or areas	
General	20
Local for reading	30
X-ray suite	
Radiographic, general	10
Fluoroscopic, general (variable)	0-50
Deep and superficial therapy	10
Control room	10
Film viewing room	30
Darkroom	10
Light room	30
Filing room, developed films	30
Storage, undeveloped films	10
Dressing rooms	10
Hotels	
Bathrooms	
Mirror	30
General	10
Bedrooms	
Reading (books, magazines, newspapers)	30
Inkwriting	30
Make-up	30
General	10
Corridors, elevators, and stairs	20
Entrance foyer	30
Front office	50
Linen room	
Sewing	100
General	20
Lobby	
General lighting	10
Reading and working areas	30
Marquee	
Dark surroundings	30
Bright surroundings	50
Ice making: engine and compressor room	20
Inspection	
Ordinary	50
Difficult	100
Highly difficult	200
Very difficult	500*
Most difficult	1000*
Iron and steel manufacturing	
Open hearth	
Stock yard	10
Charging floor	20
Pouring slide	
Slag pits	20
Control platforms	30
Mold yard	5
Hot top	30
Hot top storage	10
Checker cellar	10
Buggy and door repair	30
Stripping yard	20
Scrap stockyard	10
Mixer building	30
Calcining building	10
Skull cracker	10
Rolling mills	
Blooming, slabbing, hot strip, hot sheet	30
Cold strip, plate	30
Pipe, rod, tube, wire drawing	50
Merchant and sheared plate	30
Tin plate mills	
Tinning and galvanizing	50
Cold strip rolling	50
Motor room, machine room	30
Inspection	
Black plate, bloom and billet chipping	100
Tin plate and other bright surfaces	200*
Jewelry and watch manufacturing	500*
Kitchens (see Foodservice facilities or Residences)	
Laundries	
Washing	30
Flat work ironing, weighing, listing, marking	50
Machine and press finishing, sorting	70
Fine hand ironing	100
Leather manufacturing	
Cleaning, tanning and stretching, vats	30
Cutting, fleshing and stuffing	50
Finishing and scarfing	100
Leather working	
Pressing, winding, glazing	200
Grading, matching, cutting, scarfing, sewing	300*
Library	
Reading areas	
Reading printed material	30
Study and note taking	70
Conference areas	30
Seminar rooms	70
Book stacks (30 inches above floor)	
Active stacks	30
Inactive stacks	5
Book repair and binding	70
Cataloging	70
Card files	100
Carrels, individual study areas	70
Circulation desks	70
Rare book rooms-archives	
Storage areas	30
Reading areas	100

*Minimum on the task at any time for young adults with normal and better than 20/30 corrected vision.

Area	Footcandles on tasks*
Map, picture, and print rooms	
Storage areas	30
Use areas	100
Audiovisual areas	
Preparation rooms	70
Viewing rooms (variable)	70
Television receiving room (shield viewing screen)	70
Audio listening areas	
General	30
For note taking	70
Record inspection table	100
Microform areas	
Files	70
Viewing areas	30
Locker rooms	20
Machine shops	
Rough bench and machine work	50
Medium bench and machine work, ordinary automatic machines, rough grinding, medium buffing and polishing	100
Fine bench and machine work, fine automatic machines, medium grinding, fine buffing and polishing	500
Extra-fine bench and machine work, grinding, fine work	1000
Materials handling	
Wrapping, packing, labeling	50
Picking stock, classifying	30
Loading, trucking	20
Inside truck bodies and freight cars	10
Meat packing	
Slaughtering	30
Cleaning, cutting, cooking, grinding, canning, packing	100
Municipal buildings: fire and police	
Police	
Identification records	150
Jail cells and interrogation rooms	30
Fire hall	
Dormitory	20
Recreation room	30
Wagon room	30
Museums (see Art galleries)	
Nursing homes	
Corridors and interior ramps	20
Stairways other than exits	30
Exit stairways and landings, on floor	5
Doorways	10
Administrative and lobby areas day	50
Administrative and lobby areas, night	20
Chapel or quiet areas, general	5
Chapel or quiet area, local for reading	30
Physical therapy	20
Occupational therapy	30
Work table, course work	100
Work table, fine work	200
Recreation area	50
Dining area	30
Patient care unit (or room), general	20
Patient care room, reading	30
Nurse's station, general	
Day	50
Night	20
Nurse's desk, for charts and records	70
Nurse's medicine cabinet	100
Utility room, general	20
Utility room, work counter	50
Pharmacy area, general	30
Pharmacy, compounding, and dispensing area	100
Janitor's closet	15
Toilet and bathing facilities	30
Barber and beautician areas	50
Offices	
Drafting rooms	
Detailed drafting and designing, cartography	200
Rough layout drafting	150
Accounting offices	
Auditing, tabulating, bookkeeping, business machine operation, computer operation	150
General offices	
Reading poor reproductions, business machine operation, computer operation	150
Reading handwriting in hard pencil or on poor paper, reading fair reproductions, active filing, mail sorting	100
Reading handwriting in ink or medium pencil on good quality paper, intermittent filing	70
Private offices	
Reading poor reproductions, business machine operation	150
Reading handwriting in hard pencil or on poor paper, reading fair reproductions	100
Reading handwriting in ink or medium pencil on good quality paper	70
Reading high-contrast or well-printed materials	30
Conferring and interviewing	30
Conference rooms	
Critical seeing tasks	100
Conferring	30
Note-taking during projection (variable)	30
Corridors	20
Packing and boxing (see Materials handling)	

*Minimum on the task at any time for young adults with normal and better than 20/30 corrected vision.

Areas	Footcandles on tasks*
Paint manufacturing	
General	30
Comparing mix with standard	200
Paint shops	
Dripping simple spraying, firing	50
Rubbing, ordinary hand painting and finishing art, stencil and special spraying	50
Fine hand painting and finishing	100
Extra-fine hand painting finishing	300
Paper-box manufacturing	
General manufacturing area	50
Paper manufacturing	
Beaters, grinding, calendering	30
Finishing, cutting, trimming, papermaking machines	50
Hand counting, wet end of paper machine	70
Paper machine reel, paper inspection, and laboratories	100
Rewinder	150
Plating	30
Polishing and burnishing	100
Power plants (see Central station)	
Post Offices	
Lobby, or tables	30
Sorting, mailing, etc.	100
Poultry industry (see also Farm-dairy)	
Brooding, production, and laying houses	
Feeding, inspection, cleaning	20
Charts and records	20
Thermometers, thermostats, time clocks	50
Hatcheries	
General area and loading platform	20
Inside incubators	30
Dubbing station	150
Sexing	1000
Egg handling, packing, and shipping	
General cleanliness	50
Egg quality inspection	50
Loading platform, egg storage area, etc.	20
Egg processing	
General lighting	70
Fowl processing plant	
General (excluding killing and unloading area)	70
Government inspection station and grading stations	100
Unloading and killing area	20
Feed storage	
Grain, feed rations	10
Processing	10
Charts and records	30
Machine storage area (garage and machine shed)	5
Printing industries	
Type foundries	
Matrix making, dressing type	100
Front assembly: sorting	50
Casting	100
Printing plants	
Color inspection and appraisal	200
Machine composition	100
Composing room	100
Presses	70
Imposing stones	150
Proofreading	150
Electrotyping	
Molding, routing, finishing, leveling molds, trimming	100
Blocking, tinning	50
Electroplating, washing, backing	50
Photoengraving	
Etching, staging, blocking	50
Routing, finishing, proofing	100
Tint laying, masking	100
Professional offices (see Hospitals)	
Receiving and shipping (see Materials handling)	
Residences	
Specific visual tasks*	
Dining	15
Grooming, shaving, make-up	50
Handcraft	
Ordinary seeing tasks	70
Difficult seeing tasks	100
Very difficult seeing tasks	150
Critical seeing tasks	200
Ironing (hand and machine)	50
Kitchen duties	
Food preparation and cleaning	150
Serving and other non-critical tasks	50
Laundry	
Preparation, sorting inspection	50
Tub area: soaking, tinting	50
Washer and dryer areas	30
Reading and writing	
Handwriting, reproductions, and poor copies	70
Books, magazines, newspapers	30
Reading piano or organ scores	
Advanced (substandard size)	150
Advanced	70
Simple	30
Sewing (hand and machine)	
Dark fabrics	200
Medium fabrics	100
Light fabrics	50
Occasional: high contrast	30
Study	70
Table games	30

*Minimum on the task at any time for young adults with normal and better than 20/30 corrected vision.

Areas	Footcandles on tasks*
General lighting	
Conversation, relaxation, entertainment	10
Passage areas, for safety	10
Areas involving visual tasks, other than kitchen	30
Kitchen	50
Restaurants (see Food service facilities)	
Rubber goods-mechanical	
Stock preparation	
Plasticating, milling, Banbury	30
Calendering	50
Fabric preparation, stock cutting, hose looms	50
Extruded products	50
Molded products and curing	50
Inspection	200
Rubber tire manufacturing	
Banbury	30
Tread stock	
General	50
Booking and inspection, extruder, check weighing, width measuring	100
Calendering	
General	30
Letoff and windup	50
Stock cutting	
General	30
Cutters and splicers	100
Bead Building	50
Tire Building	
General	50
At machines	150
In-process stock	30
Curing	
General	30
At molds	70
Inspection	
General	100
At tires	300
Storage	20
Sawmills	
Grading redwood lumber	300
Schools	
Tasks	
Reading printed material	30
Reading pencil writing	70
Spirit duplicated material	
Good	30
Poor	100
Drafting, benchwork	100
Lip reading, chalkboards, sewing	150
Classrooms	
Art rooms	70
Drafting rooms	100
Home economics rooms	
Sewing	150
Cooking	50
Ironing	50
Sink activites	70
Note-taking areas	70
Laboratories	100
Lecture rooms	
Audience area	70
Demonstration area	150
Music rooms	
Simple scores	30
Advanced scores	70
Shops	100
Sight-saving rooms	150
Study halls	70
Typing	70
Corridors and stairways	20
Dormitories	
General	10
Reading books, magazines, newspapers	30
Study desk	70
Service space (see also Storage rooms)	
Stairways, corridors	20
Elevators, freight and passenger	20
Toilets and wash rooms	30
Service stations	
Service bays	30
Sales room	50
Shelving and displays	100
Rest rooms	15
Storage	5
Sheet metal works	
Miscellaneous machines, ordinary bench work	50
Presses, shears, stamps, spinning, medium bench work	50
Punches	50
Tin plate inspection, galvanized	200
Scribing	200
Shoe manufacturing: leather	
Cutting and stitching	
Cutting tables	300
Marking, buttonholding, skiving, sorting, vamping, counting	300
Stitching, dark materials	300
Making and finishing, nailers, sole layers, welt beaters and scarfers, trimmers, welters, lasters, edge setters, sluggers, randers, wheelers, treers, cleaning, spraying, buffing, polishing, embossing	200
Shoe manufacturing: rubber	
Washing, coating, mill run compounding	30
Varnishing, vulcanizing, calendering, upper and sole cutting	50
Sole rooling, lining, making and finishing processes	100
Show windows*	
Daytime lighting	
General	200
Feature	1000

*Minimum on the task at any time for young adults with normal and better than 20/30 corrected vision.

Area	Footcandles on tasks
Nighttime lighting	
Main business districts-highly competitive	
General	200
Feature	1000
Secondary business districts or small towns	
General	100
Feature	500
Open-front stores (see display lighting under Stores)	
Soap manufacturing	
Kettle houses, cutting, soap chip and powder	30
Stamping, wrapping and packing, filing and packing soap powder	50
Stairways (see Service space)	
Steel (see Iron and steel)	
Stone crushing and screening	
Belt conveyor tubes, main line shafting spaces, chute rooms, inside of bins	10
Primary oreaker room, auxiliary beakers under bins	10
Screens	20
Storage battery manufacturing	
Molding of grids	50
Storage rooms or warehouses	
Inactive	5
Active	
Rough bulky	10
Medium	20
Fine	50
Stores	
Circulation areas	30
Merchandising areas	
Service	100
Self-service	200
Showcases and wall cases	
Service	200
Self-service	500
Feature displays	
Service	500
Self-service	1000
Alteration room	
General	50
Pressing	150
Sewing	200
Fitting room	
Dressing areas	50
Fitting areas	200
Stockrooms	30
Structural steel fabrication	50
Sugar refining	
Grading	50
Color inspection	200
Television (see Section 24)	
Testing	
General	50
Extra-fine instruments, scales, etc.	200
Textile mills-cotton	
Opening, mixing, picking	30
Carding and drawing	50
Slubbing, roving, spinning, spooling	50
Beaming and splashing on comb	
Gray goods	50
Denims	150
Inspection	
Gray goods (hand turning)	100
Denims (rapidly moving)	500
Automatic tying-in	150
Weaving	100
Drawing-in by hand	200
Textile mills-silk and synthetics	
Manufacturing	
Soaking, fugitive tinting, and conditioning or setting of twist	30
Winding, twisting, rewinding and coning, quilling, slashing	
Light thread	50
Dark thread	200
Wraping (silk or cotton system)	
On creel, on running ends, on reel, on beam, on warp at beaming	100
Drawing-in on heddles and reed	200
Weaving	100
Textile mills-woolen and worsted	
Opening, blending, picking	30
Grading	100
Carding, combing, recombing and gilling	50
Drawing	
White	50
Colored	100
Spinning (frame)	
White	50
Colored	100
Spinning (mule)	
White	50
Colored	100
Twisting	
White	50
Winding	
White	30
Colored	50
Warping	
White	100
White (at reed)	100
Colored	100
Colored (at reed)	300
Weaving	
White	100
Colored	200
Gray-goods room	
Burling	150
Sewing	300
Folding	70

*Minimum on the task at any time for young adults with normal and better than 20/30 corrected vision.

Area	Footcandles on tasks*
Wet finishing, fulling, scouring, crabbing, drying	50
Dyeing	100
Dry finishing, napping, conditioning, pressing	70
Dry finishing, shearing	100
Inspecting (perching)	2000
Folding	70
Theatres and motion picture houses	
Auditoriums	
During intermission	5
During picuture	0.1
Foyer	5
Lobby	20
Tobacco products	
Drying, stripping, general	30
Grading and sorting	200
Toilets and wash rooms	30
Upholstering-automobile, coach, furniture	100
Warehouse (see Storage rooms)	
Welding	
General illumination	50
Precision manual arc welding	1000
Woodworking	
Rough sawing and bench work	30
Sizing, planing, rough sanding, medium quality machine and bench work, gluing, veneering, cooperage	50
Fine bench and machine work, fine sanding and finishing	100

*Minimum on the task at any time for young adults with normal and better than 20/30 corrected vision.

TEST

Write true, or false, in the blank at the end of each statement in Items 1-7.

1. The most effective first step in any lighting management program should be to modify maintenance procedures. ________
2. Nonuniform illumination should be considered only in circulation or support areas. ________
3. Single-wattage lamps produce more lumens per watt, as a general rule, than do multi-level lamps. ________
4. The coefficient of utilization is a measurement of illumination per unit of time. _______
5. A light meter can be used to determine the percentage of veiling glare. _______
6. Permanent desk locations could contribute to efficient lighting system design. ________
7. Lenses reduce veiling reflections and also reduce effective wattage of the lamps to which they are applied. ________

8. When 40-watt fluorescent tubes are replaced with an equal number of 35-watt energy-efficient tubes, a 14% savings occurs. For every 1000 watts of lighting energy saved, an additional 300 watts of cooling energy is saved (assuming the example to be in Texas). In this particular case, 4200 watts of 40-watt tubes were replaced in a situation that requires lights be used 1050 hours per cooling season (1000 watts = 1 kilowatt). The savings resulting from this energy conservation measure is ...

a. 807.96 kWh/season.
b. 921.53 kWh/season.
c. 802.62 kWh/season.
d. 767.17 kWh/season.
e. 829.56 kWh/season.

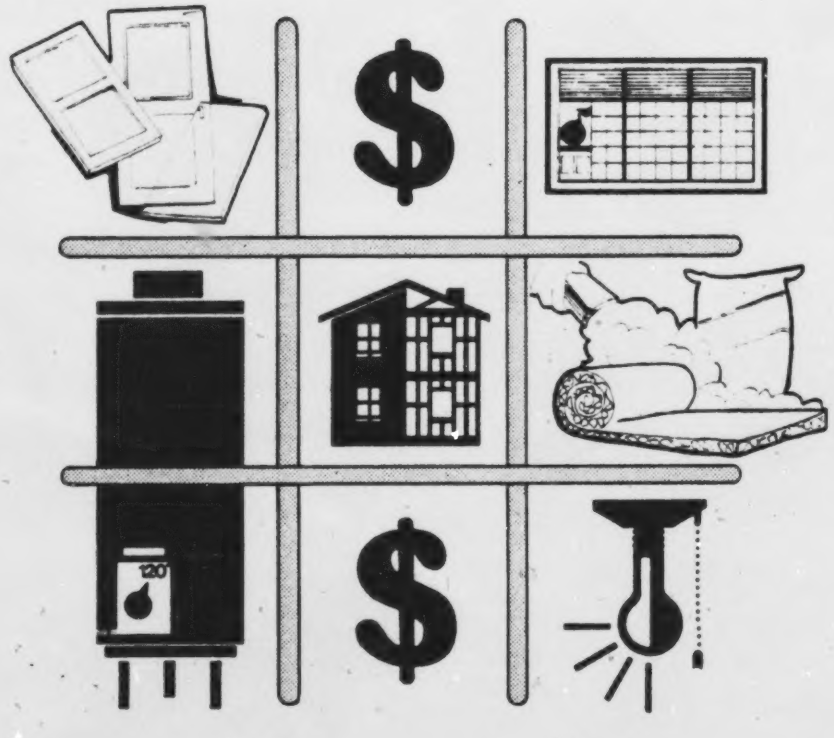
9. Match items from column B with those in Column A. Enter answers in the blanks beside each item in column A. There may be more than one matching item from B for each item in A.

Column A		Column B
____ Fluorescent lamp	a.	Tungsten filament
____ Low-pressure sodium	b.	Phosphor coating
____ Mercury lamp	c.	CRI 100
____ Incandescent lamp	d.	Start-up delay
____ Natural light	e.	CRI 97
____ High-pressure sodium	f.	Lumens per watt
	g.	Ellipsoidal reflector
	h.	HID
	i.	CRI 0
	j.	Bulb-darkening
	k.	Discharge
	l.	CRI 75

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY AUDITS



MODULE EA-06

AUDITING HVAC SYSTEMS - PART 1

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

Because HVAC systems are complex, and also because they are by far the largest energy users in any building energy system, the HVAC section of the Energy Audits course is divided into two modules. "HVAC Systems Part I" deals with the different types of HVAC systems and outlines energy efficiency design and modification suggestions.

PREREQUISITES

The student should have completed Module EA-05, "Lighting Systems."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Define and describe the major types of new and existing HVAC systems.
2. Discuss general efficiency modification considerations and specific modifications made to improve the efficiency of the most common HVAC system types.
3. Describe the different types of heating equipment.
4. Describe the different types of distribution systems and discuss inspection procedures for each.

HVAC AND BUILDING ENERGY USE

By far the biggest energy user in any building is the HVAC - heating, ventilating, and air conditioning - system. HVAC, the environmental control system, often comprises 60% of the typical building's energy usage.

Two facts are particularly important:

1. Because of the complexity and high energy consumption of HVAC units, maintenance procedures are especially important to efficient - and thus less expensive - operation.
2. Most of today's public buildings have HVAC systems that were designed when energy was cheap. The rationale behind building these systems with poor weatherization was that fuel costs were less than the initial capital investment.

Therefore, needed improvements are not difficult to locate. And common sense, or logic, is by far the most important tool the auditor needs.

GENERAL HVAC SYSTEMS DESCRIPTION AND MODIFICATION SUGGESTIONS

The following are comments about the major elements of the heating, ventilating, and air conditioning systems, and the various types of equipment found in each:

SINGLE ZONE SYSTEM

A zone is an area or group of areas in a building that experience similar amounts of heat gain and heat loss. A single zone system (Figure 1) is one that provides heating and cooling to one zone that is controlled by a zone thermostat. The unit may be installed within, or remote from, the space it serves — either with or without air distribution ductwork.

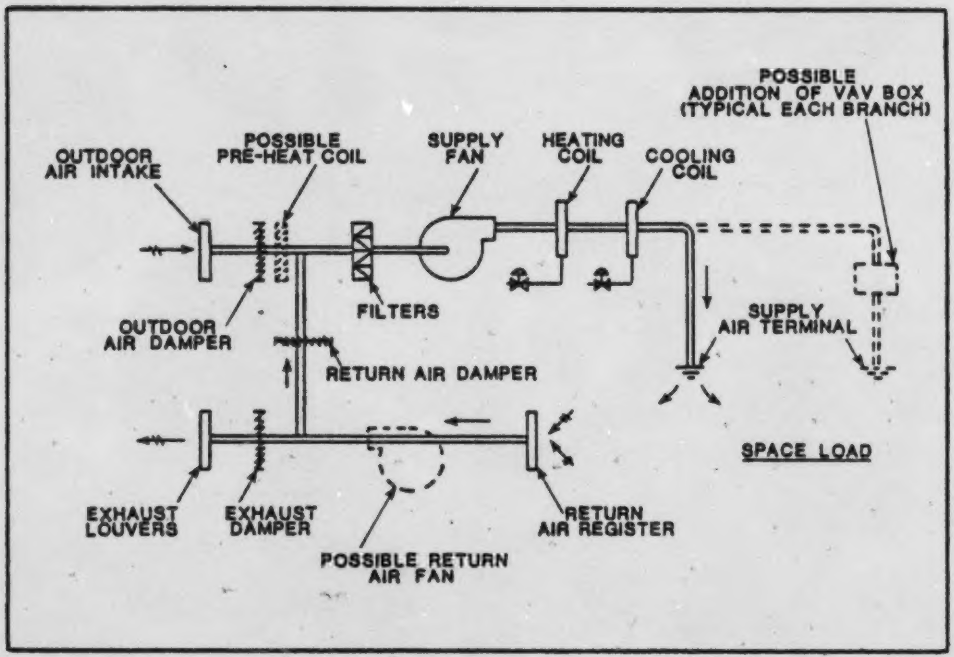

POSSIBLE ADDITION OF VAV BOX (TYPICAL EACH BRANCH)
OUTDOOR AIR INTAKE
POSSIBLE PRE-HEAT COIL
SUPPLY FAN
HEATING COIL
COOLING COIL
FILTERS
SUPPLY AIR TERMINAL
OUTDOOR AIR DAMPER
RETURN AIR DAMPER
SPACE LOAD
EXHAUST LOUVERS
EXHAUST DAMPER
RETURN AIR REGISTER
POSSIBLE RETURN AIR FAN

Figure 1. Single Zone System.

Steps that can be taken to make a single zone system function efficiently include the following modifications:

- In some systems, air volume may be reduced to minimum required, thereby reducing fan power input requirements. Fan brake horsepower varies directly with the cube of air volume. Thus, for example, a 10% reduction in air volume permits a 27% reduction of original fan power input. This modification limits the degree to which the zone serviced can be heated or cooled (as compared to current capabilities).
- Raising supply air temperatures during the cooling season and reducing them during the heating season reduces the amount of heating and cooling that a system must provide. But, as with air volume reduction, this practice limits heating and cooling capabilities.
- Using the cooling coil for both heating and cooling by modifying the piping enables removal of the heating coil, which provides energy savings in two ways. First, airflow resistance of the entire system is reduced so that air volume requirements can be met by lowered fan speeds. Second, system heat losses are reduced because the surface area of cooling coils is much larger than that of heating coils, enabling lower water temperature requirements. Heating coil removal is not recommended if humidity control is critical in the zone serviced and alternative humidity control measures will not suffice.

MULTI-ZONE SYSTEM

A multi-zone system (Figure 2) heats and cools several zones – each with different load requirements – from a single, central unit. A thermostat in each zone controls dampers at the unit that mix the hot air off the heating coil, (i.e., hot deck), and cold air off the cooling coil, (i.e., cold deck), to meet the varying load requirements of the zone involved. Steps that can be taken to improve energy efficiency of multi-zone systems include the following:

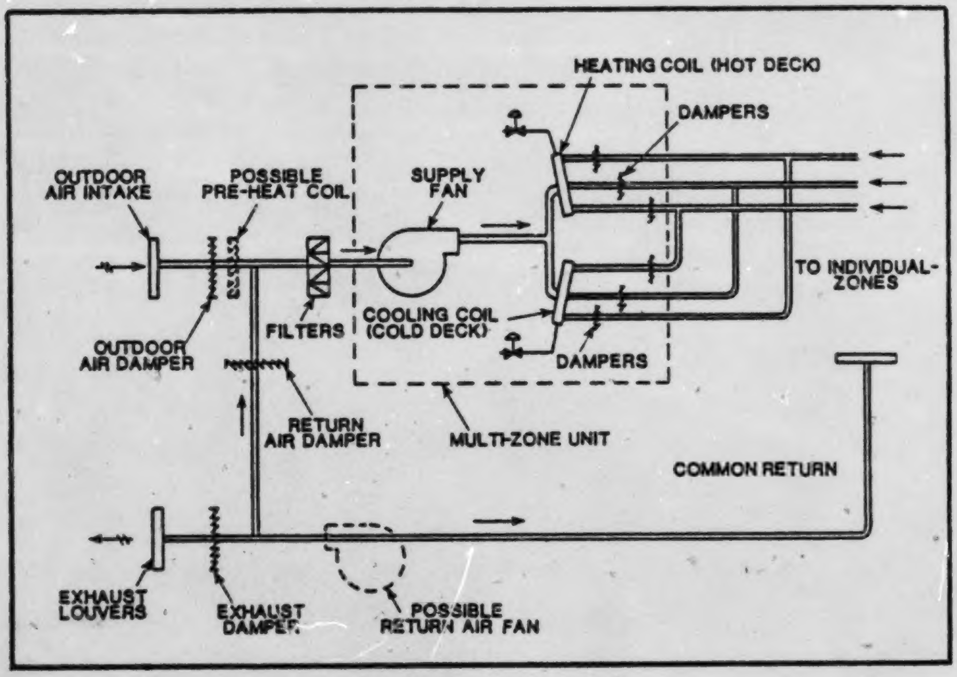

HEATING COIL (HOT DECK)
DAMPERS
OUTDOOR AIR INTAKE
POSSIBLE PRE-HEAT COIL
SUPPLY FAN
TO INDIVIDUAL-ZONES
COOLING COIL (COLD DECK)
FILTERS
OUTDOOR AIR DAMPER
DAMPERS
RETURN AIR DAMPER
MULTI-ZONE UNIT
COMMON RETURN
EXHAUST LOUVERS
EXHAUST DAMPER
POSSIBLE RETURN AIR FAN

Figure 2. Multi-Zone System.

- Reduce hot deck temperatures and increase cold deck temperatures. While this lowers energy consumption, it also reduces the system's heating and cooling capabilities (as compared to current capabilities).
- Consider installing demand reset controls that will regulate hot and cold deck temperatures according to demand. When properly installed, and with all hot deck or cold deck dampers partially closed, the control will reduce hot and raise cold deck temperatures progressively until one or more zone dampers is fully open.
- Consider converting systems serving interior zones to variable volume. Conversion is performed by blocking off the hot deck, removing or disconnecting mixing dampers, and adding low pressure variable volume terminals and a pressure bypass.

TERMINAL REHEAT SYSTEM

The terminal reheat system (Figure 3) essentially is a modification of a single zone system that provides a high degree of temperature and humidity control; however, terminal reheat is the most expensive energy, because it cools and reheats the same air or water. The central heating/cooling unit provides air at a given temperature to all zones served by the system. Secondary terminal heaters then reheat air to a temperature compatible with the load requirements of the specific space involved. Obviously, the high degree of control provided by this system requires an excessive amount of energy. Several methods of making the system more efficient include the following:

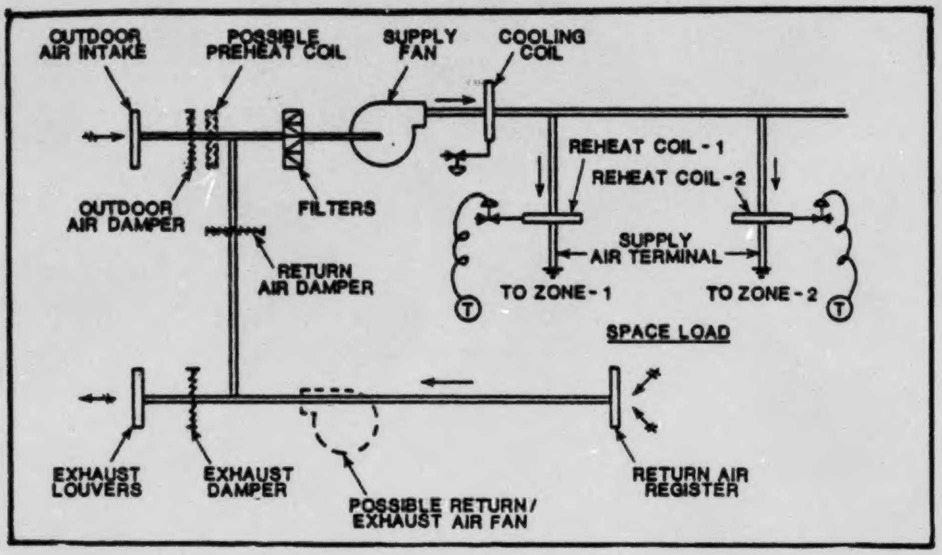

OUTDOOR AIR INTAKE
POSSIBLE PREHEAT COIL
SUPPLY FAN
COOLING COIL
REHEAT COIL - 1
REHEAT COIL - 2
OUTDOOR AIR DAMPER
FILTERS
SUPPLY AIR TERMINAL
RETURN AIR DAMPER
TO ZONE - 1
TO ZONE - 2
T
T
SPACE LOAD
EXHAUST LOUVERS
EXHAUST DAMPER
POSSIBLE RETURN/ EXHAUST AIR FAN
RETURN AIR REGISTER

Figure 3. Terminal Reheat System.

- Reduce air volume of single zone units.
- If close temperature and humidity control must be maintained for equipment purposes, lower water temperature and reduce flow to reheat coils. This permits control, but somewhat limits the system's heating capabilities.
- If close temperature and humidity control are not required, convert the system to variable volume by adding variable volume valves and eliminating terminal heaters.

VARIABLE AIR VOLUME SYSTEM

A variable air volume (VAV) system (Figure 4) provides heated or cooled air at a constant temperature to all zones served. VAV boxes located in each zone or in each space adjust the quality of air reaching each zone or space depending on its load requirements. Methods of conserving energy consumed by this system include the following:

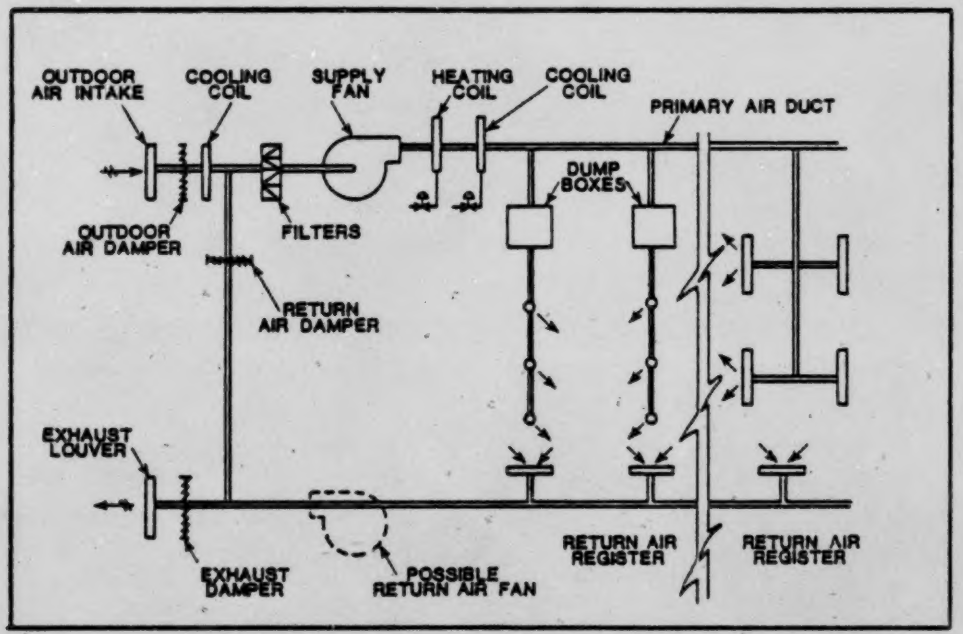

OUTDOOR AIR INTAKE
COOLING COIL
SUPPLY FAN
HEATING COIL
COOLING COIL
PRIMARY AIR DUCT
DUMP BOXES
OUTDOOR AIR DAMPER
FILTERS
RETURN AIR DAMPER
EXHAUST LOUVER
RETURN AIR REGISTER
RETURN AIR REGISTER
EXHAUST DAMPER
POSSIBLE RETURN AIR FAN

Figure 4. Variable Air Volume System.

- Reduce the volume of air handled by the system to a point that is minimally satisfactory.
- Lower hot water temperature and raise chilled water temperature in accordance with the space requirement.

- Lower air supply temperature to a point that will result in the VAV box serving the space with the most extreme load being fully open.
- Consider installing static pressure controls for more effective regulation of pressure bypass (inlet) dampers.
- Consider installing fan inlet damper control systems if none now exist.

CONSTANT VOLUME SYSTEM

Most constant volume systems either are part of another system — typically dual duct systems — or serve to provide precise air supply at a constant volume. Opportunities for conserving energy consumed by such systems include the following:

- Determine the minimum amount of airflow that is satisfactory and reset the constant volume device accordingly.
- Investigate the possibility of converting the system to variable (step controlled) constant volume operation by adding the necessary controls.

INDUCTION SYSTEMS

Induction systems (Figure 5) compose an air-handling unit that supplies heated or cooled primary air at high pressure to induction units located on the outside walls of each space served. The high-pressure primary air supplied by the

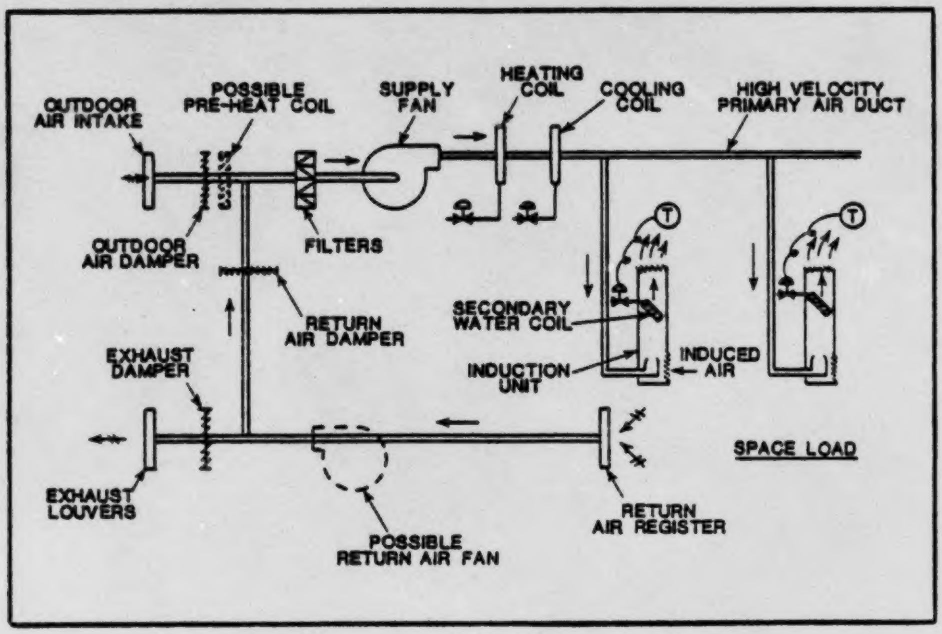

OUTDOOR AIR INTAKE
POSSIBLE PRE-HEAT COIL
SUPPLY FAN
HEATING COIL
COOLING COIL
HIGH VELOCITY PRIMARY AIR DUCT
T
T
OUTDOOR AIR DAMPER
FILTERS
RETURN AIR DAMPER
SECONDARY WATER COIL
EXHAUST DAMPER
INDUCTION UNIT
INDUCED AIR
SPACE LOAD
EXHAUST LOUVERS
RETURN AIR REGISTER
POSSIBLE RETURN AIR FAN

Figure 5. Induction System.

air-handling unit is discharged within the unit through nozzles inducing room air through a cooling or heating coil in the unit. The resulting mixture of primary air and induced, or room air (see diagram), is discharged to the room at a temperature dependent upon the cooling and heating load of the space. Methods for conserving energy consumed by this system include the following:

- Set primary air volume to original values when adjusting and balancing work is performed.
- Inspect nozzles. If metal nozzles common on most older models are installed, determine if the orifices have become enlarged from years of cleaning. If so, chances are that the volume/pressure relationship of the system has been altered. As a

result, the present volume of primary air and the appropriate nozzle pressure required must be determined. Once done, rebalance the primary air system to the new nozzle pressures and adjust individual induction units to maintain airflow temperature. Also, inspect nozzles for cleanliness. Clogged nozzles provide higher resistance to airflow, thus wasting energy.

- Set induction heating and cooling schedules to minimally acceptable levels.
- Reduce secondary water temperatures during the heating season.
- Reduce secondary water flow during maximum heating and cooling periods by pump throttling or, for dual pump systems, by operating one pump only.
- Consider manual setting of primary air temperature for heating, instead of automatic reset by outdoor or solar controllers.

DUAL DUCT SYSTEM

The central unit of a dual duct system (Figure 6) provides both heated and cooled air, each at a constant temperature. Each space is served by two ducts, one carrying hot air, the other carrying cold air. The ducts feed into a mixing box in each space that, by means of dampers, mixes hot and cold air to achieve the air temperature required to meet the load conditions in the space or zone involved. Methods for improving the energy consumption characteristics of this system include the following:

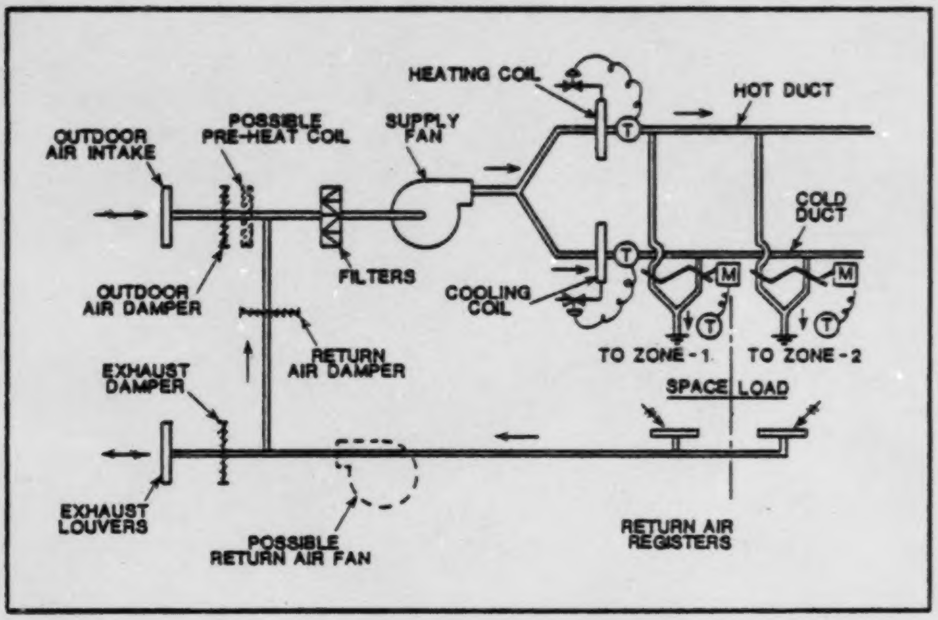

HEATING COIL
HOT DUCT
OUTDOOR AIR INTAKE
POSSIBLE PRE-HEAT COIL
SUPPLY FAN
T
COLD DUCT
T
M
M
OUTDOOR AIR DAMPER
FILTERS
COOLING COIL
T
T
RETURN AIR DAMPER
TO ZONE-1
TO ZONE-2
EXHAUST DAMPER
SPACE LOAD
EXHAUST LOUVERS
POSSIBLE RETURN AIR FAN
RETURN AIR REGISTERS

Figure 6. Dual Duct System.

- Lower hot deck temperature and raise cold deck temperature.
- Reduce airflow to all boxes to minimally acceptable level.
- When no cooling loads are present, close off cold ducts and shut down the cooling system. Reset hot deck according to heating loads and operate as a single duct system. When no heating loads are present, follow the same procedure for heating ducts and hot deck. It should be noted that operating a dual duct system as a single duct system reduces airflow, resulting in increased energy savings through lowered fan speed requirements. But operating a dual duct system as a single duct system also decreases air changes.

FAN COIL SYSTEM

A fan coil system (Figure 7) usually composes several fan coil units, each consisting of a fan and a heating and/or cooling coil. The individual units can be located either in, or remote from, the space or zone being served. Guidelines for reducing energy consumption of such systems include the following:

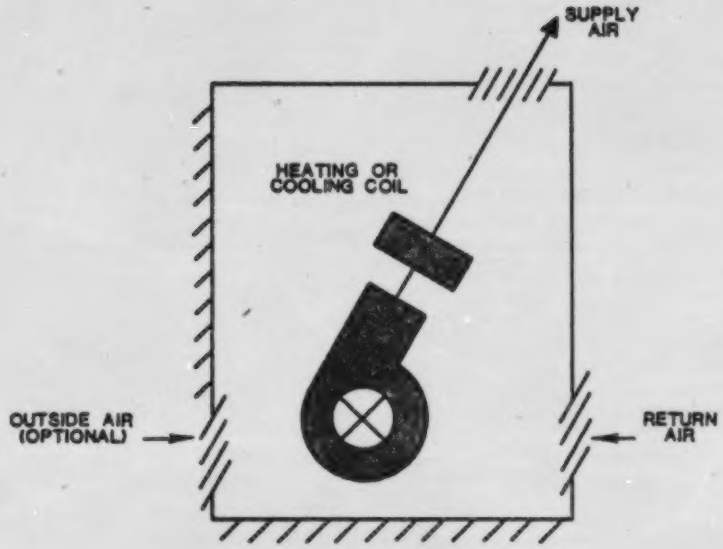

SUPPLY AIR
HEATING OR COOLING COIL
OUTSIDE AIR (OPTIONAL)
RETURN AIR

Figure 7. Fan Coil Unit.

- Reduce airflow to minimally satisfactory levels.
- Balance water flow to minimally satisfactory levels.
- When heating and cooling loads are minimal, shut OFF fans, enabling the coil to act as a convector.

- Consider installing interlocks between the heating and cooling systems of each unit to prevent simultaneous heating and cooling.
- Consider face zoning two-pipe systems from four-pipe central system to avoid changeover losses.

HEATING AND VENTILATION

There are three major areas in which energy consumption for heating and ventilation can be reduced: (1) the building heat load; (2) the distribution system load; and (3) the efficiency of the primary energy-conversion equipment.

BUILDING HEAT LOAD

One of the factors determining the building heat load is the average difference between indoor and outdoor temperature. The larger the difference, the greater the load. During the heating season, maintaining lower indoor temperatures for as long as possible reduces the heat load. Energy is conserved, for example, by lowering the indoor temperature to 68°F or less in the major areas of the building when it is occupied, and by maintaining even lower temperatures in less critical areas. Internal heat gains (heat produced by light, people, and business machines) and the amount of sunlight impinging upon the structure and transmitted through window panes and doors also reduces building heat load.

Greater energy savings can be realized by reducing indoor temperature at night and during weekends. Outdoor temperatures are generally colder at night, and neither solar heat gain nor internal heat gains help at night to offset heat loss.

Outdoor air introduced into the building for ventilation or outdoor air that infiltrates through the building envelope can also contribute to the heating load. This air must be heated and humidified to meet indoor conditions. As with other heating loads, the ultimate effect of outdoor air on the total heat load depends upon the difference in indoor and outdoor temperatures and the quantity of outdoor air introduced. In cold climates, shutting OFF ventilation air at night - when no ventilation is required for physiological reasons - may result in the single largest savings of energy.

Building heating load also depends upon the amount of mositure maintained in the building. The measure of the moisture content of the air is relative humidity (RH). When cold outdoor air enters the building, through ventilation or infiltration, relative humidity inside the building drops, and additional moisture, in vaporized form, must be added. Vaporization requires heat energy. The greater the volume of outdoor air, the greater the heat demand to supply humidification. Thus, lowering the level of humidification conserves energy.

A building is more comfortable at lower temperatures if the relative humidity is maintained at a level within a range of from 20% to 40%. In a tight building - one with little infiltration and a small amount of ventilation - the energy saved by lowering the temperature exceeds the energy required to maintain humidity levels higher than 20%. Without using a computer for seasonal analysis, however, the calculation to determine this trade-off is complicated. (See References;

ECM 2 describes a method for making this analysis.) Since there is little medical knowledge available to support the contention that relative humidities higher than 20% are more beneficial to health, the recommendation in ECM 1 is to maintain a maximum of 20% RH during the day in unoccupied areas of the building and to add no humidification at night or on weekends.

Finally, the building envelope (roof, exterior opaque walls, windows, and doors — all of which are subjected to the outdoor climate) influences the size of the building heating load. The effect of infiltration through the envelope is discussed above. In addition, heat is transmitted through the building envelope by conduction in accordance with the temperature difference between indoors and outdoors and the resistance to heat transfer offered by each of the building components.

The rate of heat transfer through the envelope is expressed as a U value — Btus/hour/square foot of surface per degree of temperature difference between indoors and outdoors. The thin layer of air surrounding the exterior surface of the envelope adds to the insulating value of the wall or roof materials. A lower U value means greater resistance to the transmission of heat and saves energy by reducing heat loss from the building.

Single panes of glass in still air (less than 15 mph) have a U value of 1.13. Double glazing reduces the U value to about 0.55. The U values of walls and roofs vary from 0.4 to 0.06, depending on the structural materials and the thickness of any insulation that has been added. Effective measures to reduce the U value and heating load include adding a storm sash to existing windows, replacing the windows with double glazing (or triple glazing in severe climate), and adding insulation to interior or exterior surfaces of roofs and exterior walls.

Wind destorys the air film around exterior surfaces and causes the U value of the surfaces to increase. Heat loss, especially through window panes and uninsulated walls, increases accordingly. Use shutters, screens, trees, or other shielding devices to reduce wind velocity on the windows to limit heat losses.

DISTRIBUTION SYSTEM LOADS

A distribution system is necessary to supply the building heating load. It may carry hot water or steam directly from a boiler to radiators or to fan coil units in the spaces to be heated, or to air-handling units that transfer the heat from the steam or hot water piping by means of coils located in the unit. Air warmed by air-handling units is forced through ducts to registers or diffusers in the conditioned spaces. Return air, drawn through ducts back to the air-handling units, is cleaned (with fresh air also drawn into the unit) by air filters. The unit, when fitted with cooling coils, employs the same blower and duct system for air conditioning. Gravity hot air furnaces deliver hot air, without a blower, directly to the space through a short duct connection. Forced warm air furnaces are equipped with a blower (through ducts similar to those of the air-handling units) to the furnace.

The distribution loads (often called parasitic loads since they do not contribute directly to the comfort and requirements of the building occupants) include heat losses from piping and ductwork, and electric power to drive fans or pumps against the resistance of the duct or piping system. Air, water, or steam leaks from these systems; torn and missing insulation; and broken or ill-fitting windows are flagrant examples of negligent waste. They increase the load without performing useful work.

The parasitic distribution loads for individual or various combinations of heating, cooling, and ventilation systems depend upon the following:

- Performance (for air systems) of the terminal room devices, air-handling units, and ductwork systems, which with fan and motor performance influence the amount of energy required for air
- Terminal devices and piping for hot water systems, which with pump and motor performance influence the amount of energy required for hot water circulation
- Piping and appurtenances for steam systems, which impose a heating load on the burner-boiler system

The same system may handle the heating, cooling, and ventilation loads at separate times or concurrently, to serve common or separate areas of a building.

Consider the opportunities for HVAC systems and distribution in the following distinct but related areas:

- Terminal Devices – Improve the performance of the terminal devices to reduce their resistance to fluid flow and increase their heat transfer characteristics.

- Ducts and Piping – Lower the resistance to flow in duct and piping systems to reduce the required horsepower for fans and pumps.
- Control Systems – Modify the control systems and modes of operation of air-handling and piping systems to reduce simultaneous heating and cooling.
- Leaks – Decrease fluid leaks and thermal losses from piping; air-handling equipment; and other vessels holding hot or cold water, air, or steam.
- Fans, Pumps, and Motors – Improve the performance of fans, pumps, and motors by maintenance and operating procedures.
- Scheduling – Reduce the hours of fan and pump operation.

Distribution Systems

A distribution system comprises the equipment and materials necessary for conveying the heating and cooling medium – water, steam, or air. Most versions of the nine general systems previously discussed employ one or more of the following distribution systems:

- Hydronic Systems – Hydronic systems are those that utilize water for transferring heating and cooling.
  Steam Systems – Steam systems are those that utilize steam as a heat source. The steam can be provided either by an on-site boiler or by district steam.
- Air Distribution Systems – Air distribution systems are those that use air for heating and/or cooling.

PRIMARY ENERGY CONVERSION EQUIPMENT

Ultimately, energy (in the form of oil, coal, or gas) is consumed by primary equipment and converted, by way of combustion, into heat in a boiler or furnace. The potential energy in the fuel is not fully realized because it is difficult to achieve and sustain the correct mix of air and fuel for combustion. Additional losses, through the breeching or smoke pipe up the chimney (and heat radiation from the boiler surfaces or furnaces jacket) further reduce the useful heat output of the unit.

Although the efficiency of a burner-furnace unit at any instant may fall just short of 90% for those fueled by oil and gas (and somewhat lower for those fueled by coal), the seasonal efficiency is generally lower by 10% to 30% as a result of stack losses during and between ON-OFF firing periods. The amount of heat lost is a function of the amount of excess air required for complete combustion, the amount of draft at maximum and part loads, the amount of air leakage into the combustion chamber, the ability of the burner to modulate in accordance with varying building loads, the quality of the fuel, and the amount of soot and scale accumulation (reducing heat transfer) on the combustion surfaces.

Proper adjustment of burners and maintenance of boilers and furnaces improve efficiency – and reduce fuel comsumption accordingly. Many units originally designed for coal, however, have been fitted with gas or oil burners and cannot be made to operate as efficiently as better quality units designed specifically for oil or gas.

After reducing the building distribution load, further improve the efficiency of the burner-boiler or furnace units by adjusting the firing rate to accommodate new loads. Lower the temperatures of the water or air delivered from the unit. Radiation and convection losses from the unit will be reduced with lowered temperature and steam pressures. If, however, it becomes necessary to circulate a greater quantity of air or water to meet room loads, distribution loads may actually increase. To analyze this trade-off thoroughly, seek professional advice. In general, operate the primary equipment at lower temperatures that are sufficient to meet room loads.

HEATING EQUIPMENT: MAINTENANCE GUIDELINES

There are also many different kinds of heating systems installed in existing office buildings and other public facilities. The following discussion centers on certain common maintenance guidelines that improve efficiency of operation.

The following are general guidelines for improving the efficiency of boilers:

- Inspect boilers for scale deposits, accumulation of sediment, or boiler compounds on waterside surfaces. The rear portion of the boiler must be checked because it is the area most susceptible to the formation of scale. (Scale reduces the efficiency of the boiler and possibly can lead to furnace overheating, cracking of tube ends, and other problems.)
- The fireside of the furnace and tubes must be inspected for deposits of soot, flyash, and slag. The fireside refractory surface also must be observed. Soot on tubes decreases heat transfer and lowers efficiency. (Consider installation of a thermometer in the vent outlet if the boiler does not have one.

A thermometer can save inspection time and often can prove to be more accurate than visual inspection alone.) If the gas outlet temperature rises above normal, it can mean that tubes need cleaning. Evidence of heavy sooting in short periods could be a signal of too much fuel and not enough air. Adjustment of the air-to-fuel ratio is required to obtain a clean-burning fire.

- Inspect door gaskets. Replace them if they do not provide a tight seal.
- Keep a daily log of pressure, temperature, and other data obtained from instrumentation. This is the best method to determine the need for tube and nozzle cleaning, pressure or linkage adjustments, and related measures. Variations from normal can be spotted quickly, enabling immediate action. On an oil-fired unit, indications of problems include an oil pressure drop, which may indicate a plugged strainer, faulty regulating valve, or an air leak in the suction line. An oil temperature drop can indicate temperature control malfunction or a fouled heating element. On a gas-fired unit, a drop in gas pressure can indicate a drop in the gas supply pressure or malfunctioning regulator.
- Note the firing rate when log entries are made. Realize that even a sharp rise in stack temperature does not necessarily mean poor combustion or fouled waterside or fireside. During a load change, stack temperatues can vary as much as 100°F in five minutes.

- Inspect stacks. They should be free of haze. If not, it is probable that a burner adjustment is necessary.
- Inspect linkages periodically for tightness. Adjust when slippage or jerky movements are observed.
- Observe the fire when the unit shuts down. If the fire does not cut off immediately, it could indicate a faulty solenoid valve. Repair or replace as necessary.
- Inspect nozzles or cup of oil-fired units on a regular basis. Clean as necessary.
- Check burner firing period. If it is improper, it could be a sign of faulty controls.
- Check boiler stack temperature. If it is too high (more than 150°F above steam or water temperature), clean tubes and adjust fuel burner.
- Check analysis of the flue gas on a periodic basis. Check oxygen and carbon monoxide, as well as carbon dioxide. Oxygen should be present to no more than 1 or 2%. There should be no carbon monoxide. For a gas-fired unit, CO_2 should be present at 9 or 10%; for #2 oil, 11.5-12.8%; for #6 oil, 13 to 13.8%.
- The air-to-fuel ratio must be maintained properly. If there is insufficient air, the fire will smoke, cause tubes to become covered with soot and carbon, and, thus, lower heat transfer efficiency. If too much air is used, unused air is heated by combustion and exhausted up the stack, wasting heat energy. Most fuel service companies will test a unit free of charge or for a token fee. (See Figure 8.)

- Inspect all boiler insulation, refractory, brickwork, and boiler casing for hot spots and air leaks. Repair and seal as necessary.
- Replace all obsolete or little-used pressure vessels.
- Examine operating procedures when more than one boiler is involved. It is far better to operate one boiler at 90% capacity than two at 45% capacity each. The more boilers used, the greater the heat loss.
- Clean mineral or corrosion build-up on gas burners.

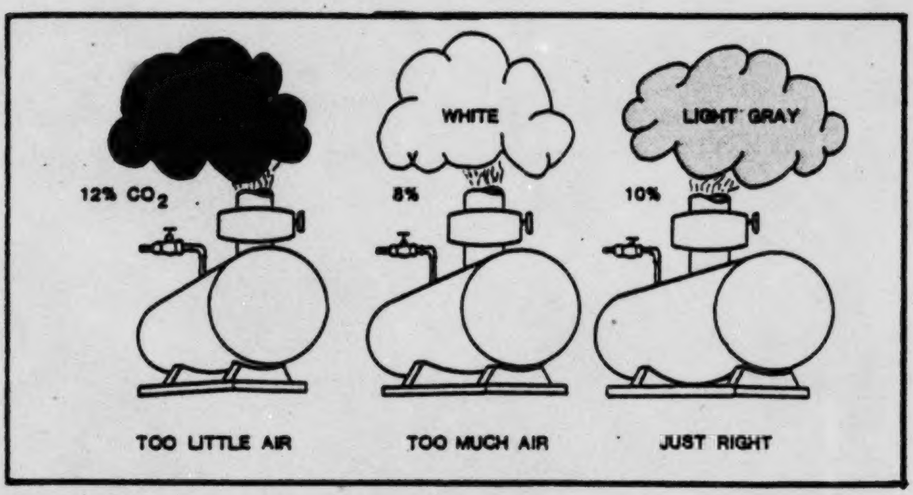


Figure 8. Boiler Air-to-Fuel Ratio.

The following are guidelines for improving the efficiency of central furnaces, make-up air heaters, and unit heaters:

- All heat exchanger surfaces should be kept clean. Check air-to-fuel ratio and adjust as necessary.
- Inspect burner couplings and linkages. Tighten and adjust as necessary.

- Inspect casing for air leaks and seal as necessary.
- Inspect insulation and repair or replace as necessary.
- Follow guidelines suggested for fan and motor maintenance.

Guidelines for improving the efficiency of radiators, convectors, baseboard, and finned-tube units are the following:

- Inspect for obstructions in front of the unit and remove them whenever possible. Air movement in and out of the convector unit must be unrestricted.
- Air will sometimes collect in the high points of hydronic units. It must be vented to enable hot water to circulate freely throughout the system. Otherwise, the units will short cycle (go ON and OFF quickly), wasting fuel.
- Heat transfer surfaces of radiators, convectors, baseboard, and finned-tube units must be kept clean for efficient operation.

The following are guidelines for improving the efficiency of electric heating:

- Keep heat transfer surfaces of all electric heating units clean and unobstructed.
- Keep air movement in and out of the units unobstructed.
- Inspect heating elements, controls, and fans (as applicable) on a periodic basis to ensure proper functioning.
- As appropriate, check reflectors on infrared heaters for proper beam direction and cleanliness.

- Determine if electric heating equipment is operating at rated voltage as necessary.
- Check controls for proper operation.

Guidelines for improving the efficiency of hot and chilled water piping are the following:

- Inspect all controls. Test the controls for proper operation. Adjust, repair, or replace the controls as necessary. Also, check for leakage at joints.
- Check flow measurement instrumentation for accuracy. Adjust, repair, or replace flow measurement instrumentation as necessary.
- Inspect insulation of hot and chilled water pipes. Repair or replace them as necessary. Be certain to replace any insulation damaged by water. Determine the source of any water leakage and correct the problem.
- Inspect strainers. Clean regularly.
- Inspect heating and cooling heat exchangers. Large temperature differences may indicate air binding, clogged strainers, or excessive amounts of scale. Determine the cause of the condition and correct it.
- Inspect vents and remove all clogs. Clogged vents retard efficient air elimination and reduce efficiency of the system.

The following are guidelines for improving the efficiency of steam piping:

- Inspect insulation of all mains, risers and branches, economizers, and condensate receiver tanks. Repair or replace as necessary.

- Check automatic temperature-control system and related control valves and accessory equipment to ensure that they are regulating the system properly in the various zones (in terms of building heating needs, not system capacity).
- Inspect zone shut-off valves. All should be operable so steam going into unoccupied spaces can be shut OFF.
- Inspect steam traps. Their failure to operate can have a significant impact on the overall efficiency and energy consumption of the system. Several different tests can be utilized to determine operations.

  a. Listen to the trap to determine if it is opening and closing when it should.

  b. Feel the pipe on the downstream side of the trap. If it is excessively hot, the trap probably is passing steam. This can be caused by dirt in the trap, valve OFF steam, excessive steam pressure, or worn trap parts (especially valve and seats). If the pipe on the downstream side of the trap is moderately hot — as hot as a hot water pipe, for example — it probably is passing condensate, which it should. If it is cold, the trap is not working at all.

  c. Check back pressure on downstream side.

  d. Measure the temperature of the return lines with a surface pyrometer. Measure the temperature drop across the trap. Lack of drop indicates steam blowthrough. Excessive drop indicates that the trap is not passing condensate. Adjust, repair, or replace all faulty traps.

Self-Contained Systems

Energy consumption of self-contained systems, such as rooftop (Figure 9), window, through-the-wall, split systems (Figure 10), and other heating and/or cooling units, can be modified as follows:

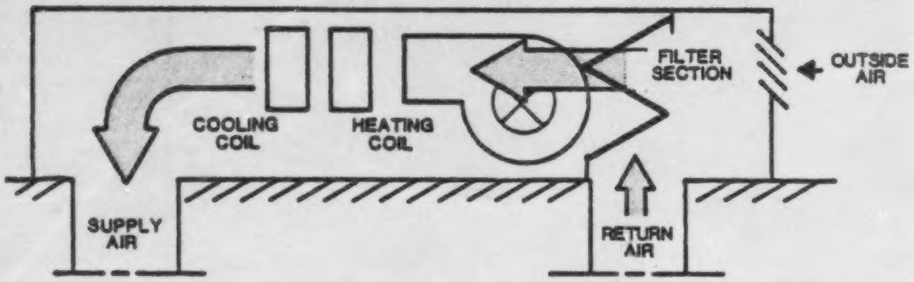

FILTER SECTION
OUTSIDE AIR
COOLING COIL
HEATING COIL
SUPPLY AIR
RETURN AIR

Figure 9. Rooftop Unit.

- If multiple units are involved, consider installation of centralized automatic shut-off and manual override control.
- If units are relatively old, consider replacing them with more efficient air-to-air heat pumps or similar units that have a higher equivalent efficiency rating.

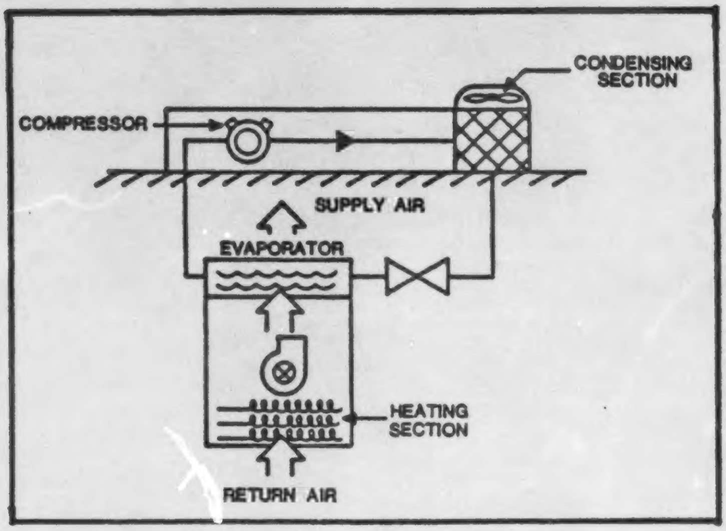

CONDENSING SECTION
COMPRESSOR
SUPPLY AIR
EVAPORATOR
HEATING SECTION
RETURN AIR

Figure 10. Split System.

234

EXERCISES

Find the yearly energy saved by lowering the temperature 10°F during unoccupied hours for the following building:

Type	Office, 40 hours occupancy/week
Location	Minneapolis, Minnesota
Floor Area	100,000 square feet
Fuel	Light Oil (138,000 Btu/gallon)
Present Heating Consumption	76,000 Btu/square feet/year
Heating Degree Days from Climatic Atlas of the U.S.	8,400

To calculate these savings, use Figure 11: "Heating – Energy saved by Night Setback."

An explanation of how Figure 11 was derived – as well as instructions for its use – follow the figure.

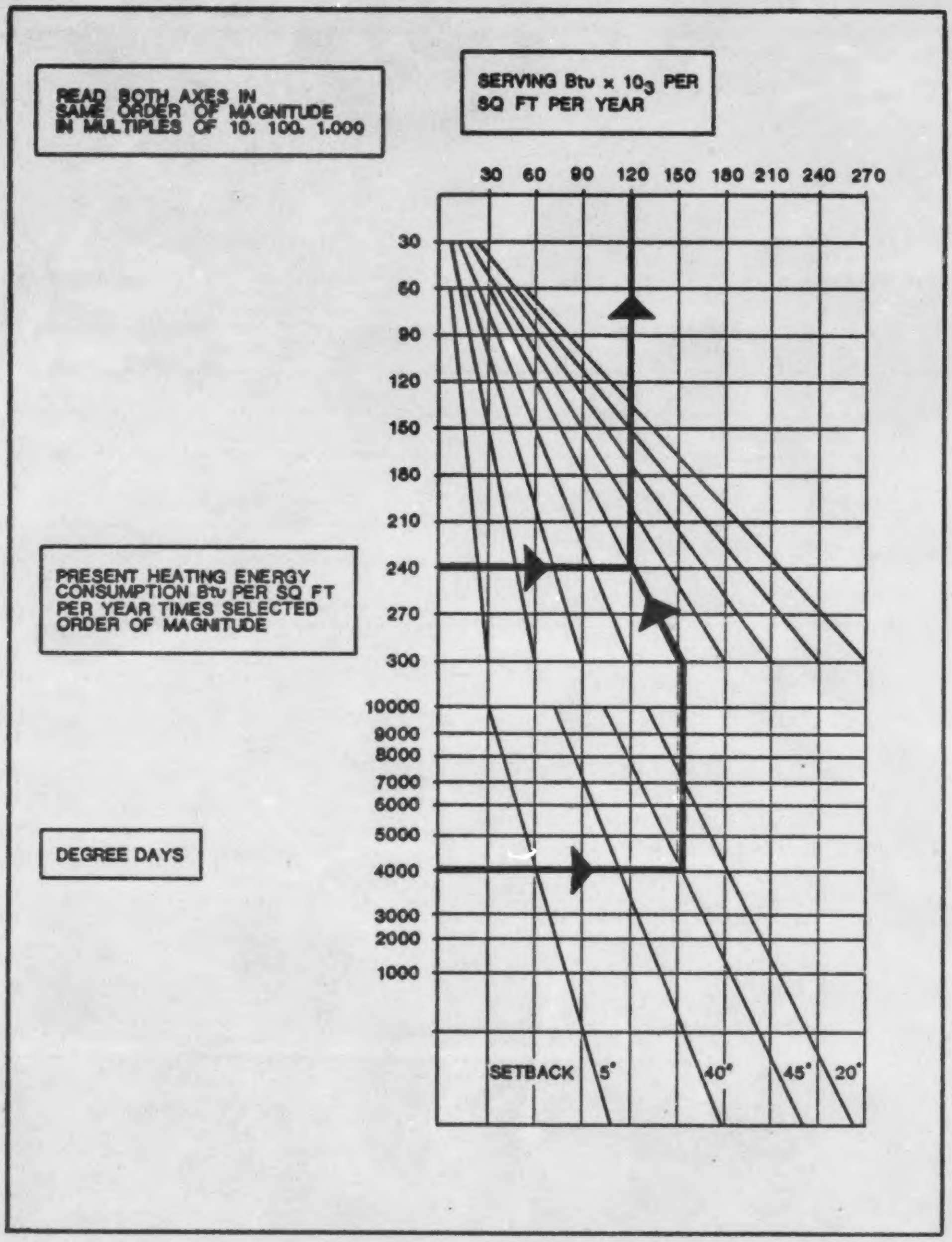


Figure 11. Heating – Energy Saved by Night Setback.

Explanation and Instructions for Figure 11:

Five locations with heating degree-day totals ranging from 1,400-8,400 were analyzed regarding time temperature distribution below 68°F DB. The percentage temperature distribution for each of the 5°F ranges, which includes the setback from 68°F shown in the lower half of the figure related to the total number of degree hours below 68°F, was determined for 24 hours per day, 365 days per year. This percentage was then plotted against annual degree days and expanded to cover the entire range of degree days. This is shown as the lower half of the figure.

The upper half of the figure represents the range of heating energy consumed per square foot for various buildings over the range of 1,000 to 10,000 degree days. The extreme right-hand line in the upper half represents 90% of the present consumption when projected vertically. Analysis of energy usage for heating by various buildings in several locations showed that it can be safely assumed that approximately 10% of the total heating energy consumption happens during occupied hours. Therefore, savings by night setback are applicable to only 90% of the total heating energy consumption. The remainder of the upper half of the figure simply proportions the energy saved based on the point of entry from the lower section.

Convert this figure to a quantity of fuel by dividing by an appropriate conversion factor. To convert to gallons of #2 oil, divide by 138,000 (the number of Btus in a gallon); for #6 oil, by 146,000 (Btus per gallon); for natural gas, by 1,000 (Btus per cubic foot); for manufactured gas, by 800 (Btus per cubic foot); and for tons of coal, by 26 x 10^6 (Btus per ton). Multiply this quantity by the unit cost for any type of energy used to calculate cost savings.

Supply the following information:

1. Enter Figure 11 at 8,400 degree days and 76,000 Btu/ft^3/yr present consumption. Intersect with the 10° setback line, and follow the example line to determine a savings of ____________.
2. Savings:
   a. Convert savings in Btus to gallons at 65% seasonal efficiency.

      _______ = _________

   b. Assuming an average fuel cost of $1.10 per gallon, the savings in dollars per year is _________.
3. Results:
   a. Energy saved: __________.
   b. Dollars saved: _________.

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TEST

Determine the energy required to heat infiltration air, using Figures 1T and 2T.

KEY TO WINDOW INFILTRATION CHART
(LEAKAGE BETWEEN SASH AND FRAME)

TYPE	MATERIAL	WEATHERSTRIPPED?	FIT
① ALL HINGED	WOOD METAL	YES YES	AVG AVG
② ALL HINGED DBL HUNG	WOOD METAL STEEL	NO NO NO	AVG AVG AVG
③ ALL DBL HUNG	WOOD STEEL	YES YES	LOOSE AVG
④ CASEMENT	STEEL	NO	AVG
⑤ ALL HINGED	WOOD	NO	LOOSE

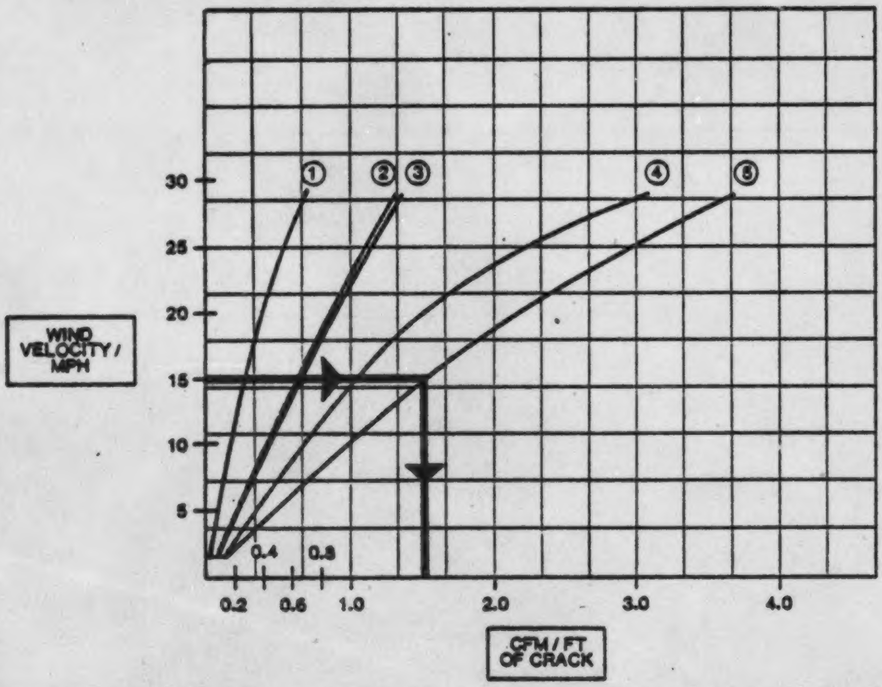


Figure 1T. Rate of Infiltration Through Window Frames.

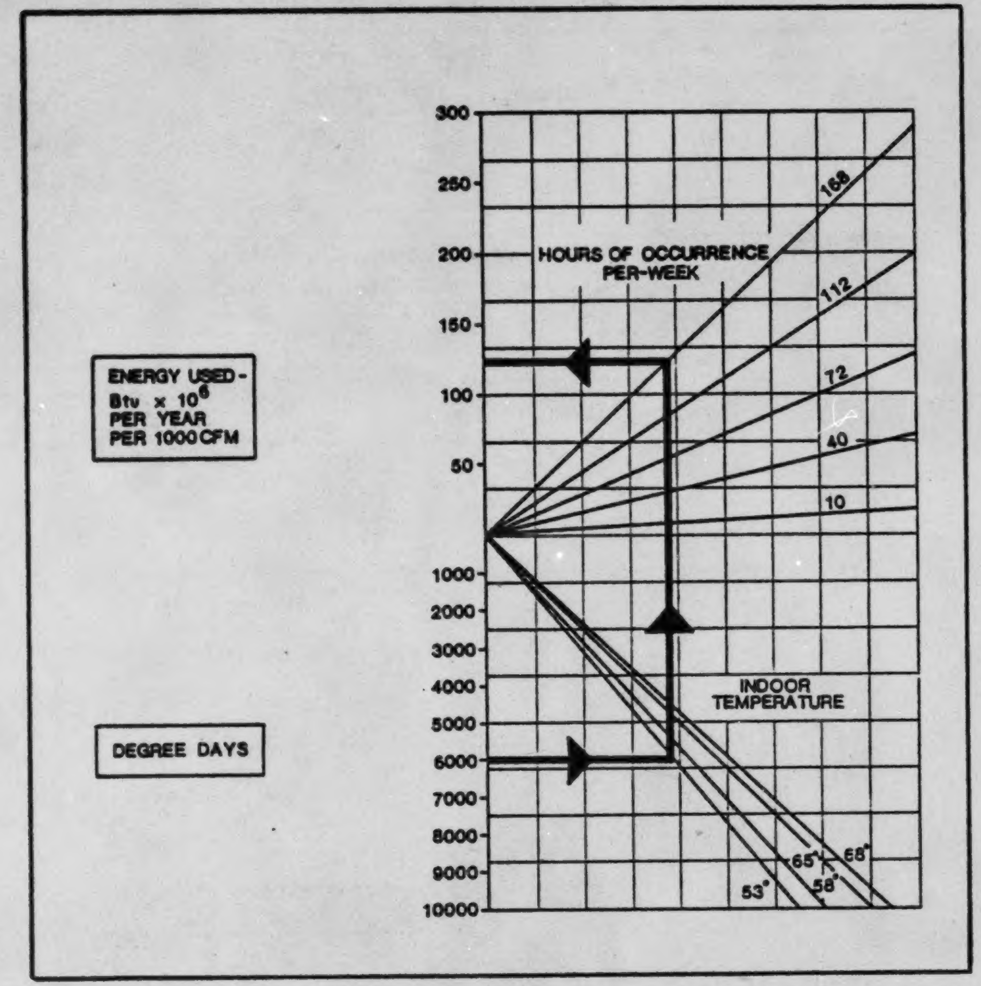


Figure 2T. Heating - Yearly Energy Used per 1,000 cfm Outdoor Air.

Use the following data to supply the information called for below. To estimate the amount of infiltration occuring in a building because of window leakage, determine, first, the total amount of crack area.

Building Type	Offices
Building Size	100' x 50' (5 floors)
Building Location	Topeka, Kansas
Heating Degree Days	5,000
Indoor Temperature	68°F
Wind Speed	15 mph
Wind Direction	NW
North Windows	Dimensions: 5' x 3'; total no. 28
West Windows	Dimensions: 5' x 3'; total no. 56
Window Type	Loose-fitting, double-hung wood sash

Circle the answer closest to your own. Figures 1T and 2T may cause some deviation.

1. The crack length per window (including the horizontal crack between the upper and lower sash) is ...
   a. 28 feet.
   b. 19 feet.
   c. 10 feet.
   d. 24 feet.

a

2. Total crack length for north and west windows is ...
   a. 2,965 feet.
   b. 1,065 feet.
   c. 982 feet.
   d. 1,596 feet.
3. Determine from Figure 1T the rate of infiltration per foot of crack.
   a. 1.5 cfm
   b. 3.9 cfm
   c. 4.2 cfm
   d. 0.3 cfm
4. Total infiltration due to window cracks is ...
   a. 4,094 cfm.
   b. 2,394 cfm.
   c. 3,294 cfm.
   d. 1,794 cfm.
5. Determine from Figure 1T the rate of infiltration per foot of crack if windows are weatherstripped.
   a. 1.03 cfm/ft
   b. 0.92 cfm/ft
   c. 0.25 cfm/ft
   d. 0.69 cfm/ft
6. Therefore, total infiltration is ...
   a. 399 cfm.
   b. 929 cfm.
   c. 614 cfm.
   d. 210 cfm.
7. Reduction in infiltration is ...
   a. 1,371 cfm.
   b. 1,592 cfm.
   c. 2,391 cfm.
   d. 1,995 cfm.

8. Determine seasonal savings in energy for heating. From Figure 2T, each 1,000 cfm required ...
   a. 1.62×10^6 Btu/year.
   b. 130×10^6 Btu/year.
   c. 219×10^6 Btu/year.
   d. 172×10^6 Btu/year.
9. Therefore, reducing infiltration by 1,995 cfm would result in a savings of ...
   a. 259.1×10^6 Btu/year.
   b. 299.2×10^6 Btu/year.
   c. 172.2×10^6 Btu/year.
   d. 111.3×10^6 Btu/year.
10. Savings due to weather stripping is ...
   a. 190.7×10^6 Btu/year.
   b. 251.3×10^6 Btu/year.
   c. 314.6×10^6 Btu/year.
   d. 228.1×10^6 Btu/year.
11. If the heating system uses #2 oil (138,000 Btus/gallon) and has a seasonal efficiency of 60%, fuel saved is ...
   a. 3,792 gallons.
   b. 3,128 gallons.
   c. 4,298 gallons.
   d. 2,771 gallons.
12. At a fuel cost of $1.10/gallon, dollars saved is ...
   a. $2948.48.
   b. $3949.48.
   c. $2194.84.
   d. $3440.80.

13. Assume the cost of weather stripping to be $25 per window. Total cost of weather stripping is ...

a. $1400.

b. $1700.

c. $2100.

d. $2900.

14. Summary: ________ (Item 12) spent on weather stripping will realize a savings in fuel cost of _________ (Item 11). Thus, capital payback will be about ...

a. 2.6 years.

b. 2.3 years.

c. 1.6 years.

d. 3.2 years.

15. On the following page, Figure 3T shows diagrams of various HVAC systems. Identify each system by entering the corresponding letter beside each item.

_____ Dual Duct System
_____ Fan Coil System
_____ Induction System
_____ Variable Volume System
_____ Multi-Zone System
_____ Split System
_____ Rooftop System
_____ Central Station, Single Zone

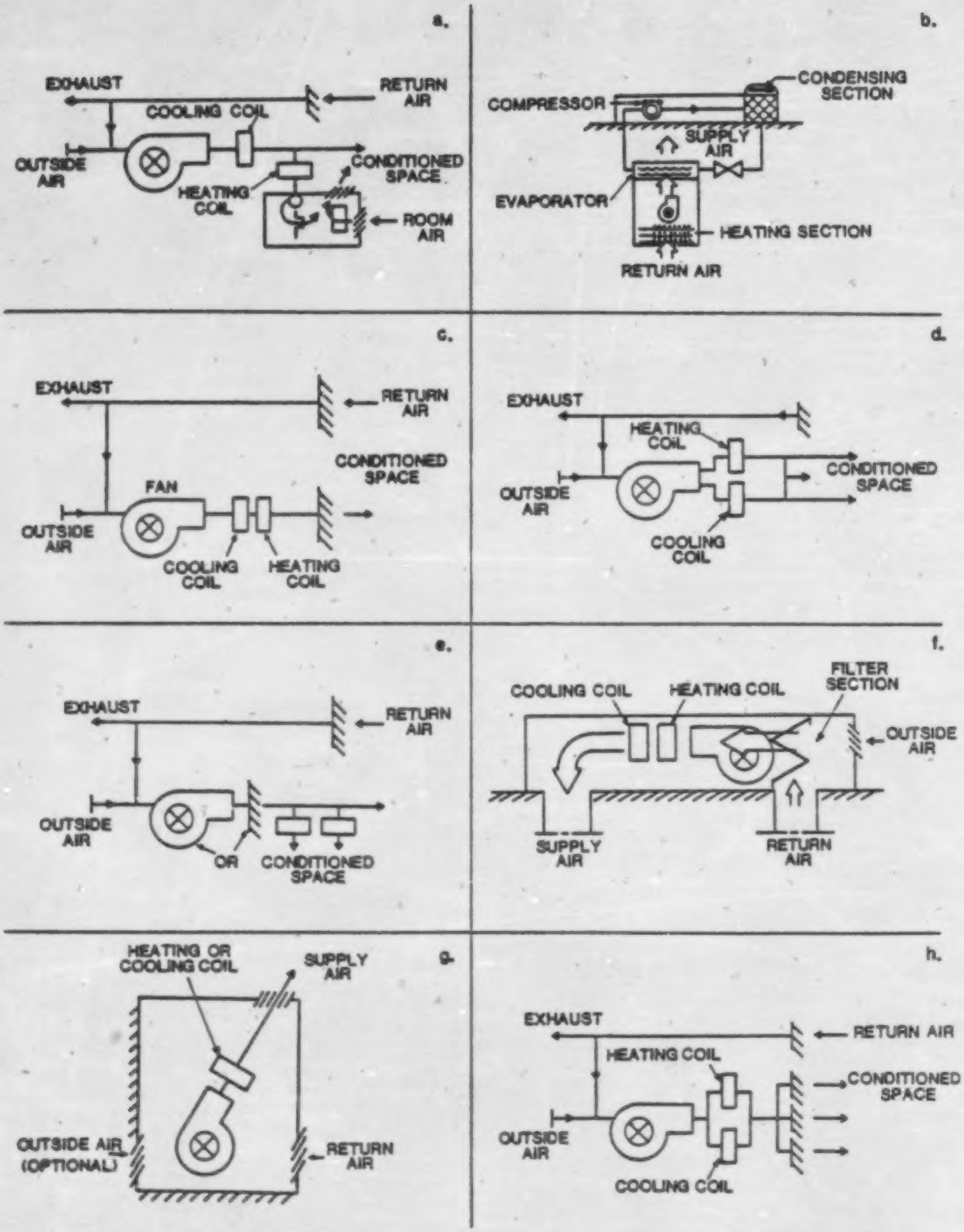
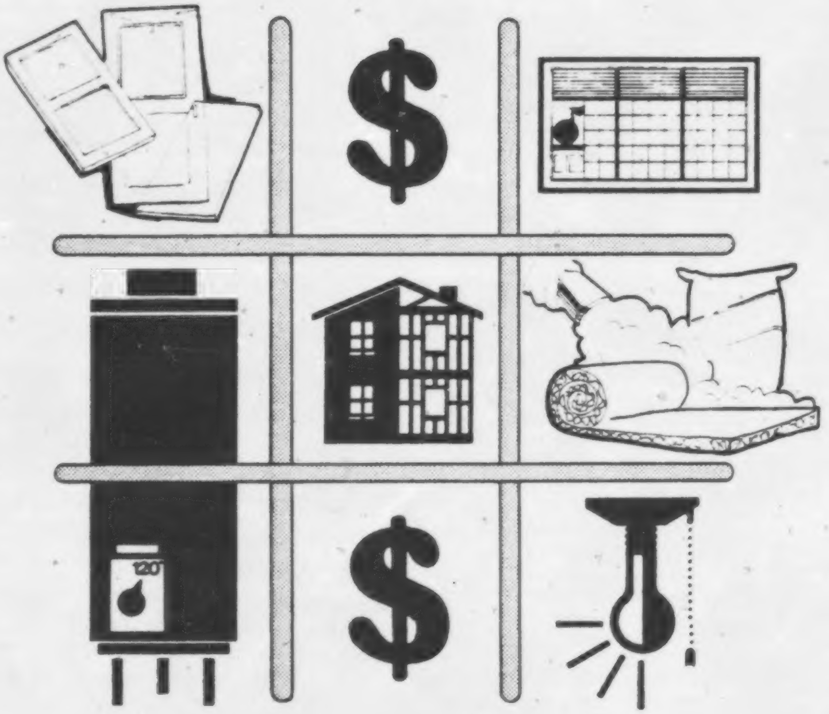

a.
EXHAUST
RETURN AIR
COOLING COIL
OUTSIDE AIR
CONDITIONED SPACE
HEATING COIL
ROOM AIR
b.
CONDENSING SECTION
COMPRESSOR
SUPPLY AIR
EVAPORATOR
HEATING SECTION
RETURN AIR
c.
EXHAUST
RETURN AIR
CONDITIONED SPACE
FAN
OUTSIDE AIR
COOLING COIL
HEATING COIL
d.
EXHAUST
HEATING COIL
OUTSIDE AIR
CONDITIONED SPACE
COOLING COIL
e.
EXHAUST
RETURN AIR
OUTSIDE AIR
OR
CONDITIONED SPACE
f.
COOLING COIL
HEATING COIL
FILTER SECTION
OUTSIDE AIR
SUPPLY AIR
RETURN AIR
g.
HEATING OR COOLING COIL
SUPPLY AIR
OUTSIDE AIR (OPTIONAL)
RETURN AIR
h.
EXHAUST
RETURN AIR
HEATING COIL
CONDITIONED SPACE
OUTSIDE AIR
COOLING COIL

Figure 3T. Diagrams of HVAC Systems.

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY AUDITS



MODULE EA-07

AUDITING HVAC SYSTEMS - PART II

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

"Auditing HVAC Systems — Part II" discusses cooling equipment and includes materials on energy-efficiency maintenance procedures. The equipment discussion is followed by material on HVAC energy conservation practices. Finally, the module contains energy efficiency guidelines for selecting new or replacement HVAC equipment.

PREREQUISITES

The student should have completed Module EA-06, "Auditing HVAC Systems — Part I."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Define and describe refrigerant equipment components and their roles in the cooling process.
2. Discuss maintenance of each component of refrigerant equipment.
3. Discuss energy-efficiency maintenance procedures for each type of heating equipment.
4. Discuss HVAC conservation practices.
5. Discuss guidelines for selection of new HVAC equipment.

COOLING AND VENTILATION: REDUCING ENERGY CONSUMPTION

Methods for reducing energy consumption for cooling and ventilation can be classified in the same major categories as for heating and ventilation:

- Reduce building cooling load.
- Reduce distribution system load.
- Increase efficiency or performance of the primary energy conversion equipment.

BUILDING COOLING LOAD

Two components determine the building cooling load: sensible (dry) heat and latent heat (a function of heat content of the moisture in the air). (Building cooling load is used to identify the loads to maintain interior conditions and should not be confused with room loads, which is standard terminology for building loads not including the ventilation load.) To maintain comfort, the dry-bulb temperature (sensible heat) and the relative humidity, or wet-bulb temperature (latent heat), must be controlled. For most comfort cooling installations, air is dehumidified when it is cooled; therefore, separate control of the relative humidity is not usually required.

The average temperature difference between indoor and outdoor conditions is one factor that defines the sensible heat gain portion of the annual building load. This load can be reduced by maintaining higher indoor temperatures for as long as possible during the cooling season, when further operation of the mechanical refrigeration system would be required to maintain a lower temperature. When the sensible heat gain is decreased, the amount of cool supply air can be reduced accordingly to realize additional energy savings in fan horsepower.

Cooling load is, in part, due to conductive heat gain from outdoors to indoors through the building envelope.

The average difference in temperature between indoors and the exterior surfaces of the walls and roof depends upon outdoor dry-bulb temperatures and the amount of solar radiation impinging upon the outside walls and roof and warming them to a level (termed "sol-air" temperatures) that is most often above ambient temperatures. To conserve energy, the refrigeration system and its auxiliaries (chilled water and condenser water pumps, cooling towers, and air-cooled condensers) should be shut off during unoccupied hours. During occupied periods, a dry-bulb temperature of 78°F or higher should be maintained.

Maintaining even higher temperatures in less critical spaces will conserve more energy. The relative humidity in a building is usually 45° to 50°. However, considerable energy will be conserved if this level is permitted to rise to 55% or to fluctuate normally within the limits set by the refrigeration system's ability to maintain wet-bulb temperatures. The system requires power to remove moisture that originates from internal loads and from outdoor air as it infiltrates and/or ventilates the building. Table 1 lists the recommended cooling season indoor temperature and humidity levels for commercial buildings and retail stores.

TABLE 1. RECOMMENDED COOLING SEASON INDOOR TEMPERATURE AND HUMIDITY.

Commercial Buildings	Occupied Periods Dry-Bulb Temperature*	Occupied Periods Minimum Relative Humidity
Offices	78°	55%
Corridors	Uncontrolled	Uncontrolled
Cafeterias	75°	55%
Auditoriums	78°	50%
Computer Rooms	75°	As needed
Lobbies	82°	60%
Doctors' Offices	78°	55%
Toilet Rooms	80°	
Storage, Equipment Rooms	Uncontrolled	
Garages	Do not cool or dehumidify	

Retail Stores	Occupied Periods Dry-Bulb Temperature	Occupied Periods Relative Humidity
Department Stores	80°	55%
Supermarkets	78°	55%
Drug Stores	80°	55%
Meat Markets	78°	55%
Apparel	80°	55%
Jewelry	80°	55%
Garages	Do not cool	

*Except where terminal reheat systems are used.

Heat gain, a term used to quantify the amount of heat added to a space, is an addition to the cooling load and must be removed in order to maintain the desired space conditions. Solar heat gain through windows frequently constitutes a major portion of the sensible heat in building cooling load. The benefits from using sunlight to reduce the heating load in winter are considerable, but the sun must be blocked out in the summer. Solar control devices can be adjusted to either accept or block sunlight to reduce energy consumption year-round.

Just as ventilation and infiltration add to the heating load in winter, they also increase cooling load in summer. Outside air must be cooled and dehumidified. Maintaining higher indoor temperatures and relative humidity reduces the cooling load contributed by infiltration and ventilation, as well as conductive heat gains. However, whenever outdoor air is cool enough to lower indoor temperatures, it may be advantageous and energy conserving to cool or pre-cool the building at night (using an economizer cycle) without mechanical refrigeration. When the wet-bulb (WB) temperature of the outdoor air is lower than the WB temperature of the return air from the interior spaces, an enthalpy controller will open the outside air dampers and close the return air dampers to take in 100% outdoor air. The controller saves power for the refrigeration system. Internal heat gains – heat emitted from electric lighting fixtures, business machines, motors, cooking equipment, and people – form a large part of the total cooling load.

Reducing the building cooling load by a fixed percentage allows further savings of energy, since distribution loads can be decreased accordingly. A reduction in the flow of cool air or chilled water to meet the reduced load and an increase in the suction temperatures at which the refrigeration chillers or compressors operate (improving their coefficient of performance) will result in significant savings – less horsepower per ton of refrigeration, as well as less tons to be produced.

DISTRIBUTION SYSTEM LOADS

The distribution system may carry chilled water to units in the spaces to be conditioned (fan coil, induction, or small air-handling units) or to remote air-handling units that supply air, via ducts, to local registers and diffusers. In some systems, the compressors discharge a vaporized refrigerant to a condenser. When the vaporized refrigerant is condensed to a liquid, it is allowed to expand directly in a cooling coil that cools or dehumidifies circulating air. In all cases, air may be circulated from the conditioned space, from outdoors, or from a mixture of both. Air is supplied after it is filtered, cooled, and dehumidified in the air-handling unit or air-handling section of the air conditioning system.

Piping and duct losses (heat gain and water or air leakage) increase distribution loads. The increased distribution load increases the load on the primary energy conversion equipment. (See Module EA-06, "Auditing HVAC Systems — Part I," for energy conservation opportunities and guidelines to reduce distribution system losses.)

PRIMARY ENERGY CONVERSION EQUIPMENT

Energy is used to supply the building cooling and distribution loads. In the form of heat, energy operates absorption refrigeration units; as electricity, energy operates reciprocating, centrifugal, or screw-type compressors and/or chillers. The refrigeration equipment produces either chilled water or, in the case of direct expansion refrigeration units with air-handling units, cooled and dehumidified air. (Note: Refrigeration equipment is often termed the "high" side of the refrigeration cycle.) The air-cooled or water-cooled condensers of the refrigeration equipment control the condensing temperature of the system. The lower the condensing temperature, the more efficient the refrigeration system. The manner and conditions under which air-cooled condensers or evaporative condensers with cooling towers are operated exert a significant influence on the energy required to run the refrigeration units. The efficiency of the refrigeration system is expressed as a coefficient of performance (COP).

The capacity of the system is measured in tons of refrigeration; one ton will produce a cooling effect equal to 12,000 Btus/hour. Seasonal COP is the ratio of the tons of refrigeration produced, expressed in Btus, to the energy required to operate the equipment, also in Btus. If one kilowatt-hour of electricity (equivalent to 3,412 Btus) is required to produce one ton of refrigeration (12,000 Btus), the COP is 12,000 ÷ 3,412 = 3.52. To improve the COP (reduce energy usage), condensing temperatures must be lowered and/or suction temperatures raised. The opportunities to do either depend upon load reduction and upon operation and maintenance of equipment. The opportunities to improve COP by reducing distribution loads are outlined in Module EA-06.

ENERGY CONSERVATION OPPORTUNITIES

Energy can be saved by turning the air conditioning system OFF at night and during days when the building is unoccupied. Energy can also be saved by manually shutting down cooling or condenser fans, chilled water and condenser pumps, and supply and exhaust fans, as well as chillers or compressors.

If the cooling tower fans and pumps are interlocked with compressors, they will turn OFF automatically when the compressors are OFF. It is best to shut down boilers that supply steam or hot water to absorption units; boiler water temperature or steam pressure should not be maintained when absorption units are inoperative. If, after shutdown, the air conditioning system is not capable of achieving and maintaining temperature and humidity conditions in hot spells, a control to activate the equipment a few hours before occupancy should be installed instead of operating the system all night or throughout the weekend.

In geographic areas, such as parts of Arizona or California, with a large diurnal swing (large temperature difference within 24 hours), night operation of the refrigeration system for periods of the summer may be economical. If climatic conditions at night permit lower condensing temperatures, an analysis should be made to determine whether energy can be saved by operating the refrigeration system at night to pre-cool the building or to store chilled water in the piping system.

An engineering and economic analysis, comparing refrigeration operation and economizer cooling, is necessary to determine which method will produce minimum energy consumption.

When nighttime outdoor temperatures are below indoor temperatures by 5° or more, shutting off the refrigeration system and using outdoor air for night cooling will save energy in most geographic regions. Opportunities to use outdoor air for cooling during unoccupied periods depend upon the length of time that the outdoor air temperature is below 73°F. In most areas, there will be no advantage to bringing in outdoor air above that temperature; heat from the fan motors will raise the air temperature 2° to 3°. The power required to drive the fans will outweigh any savings due to pre-cooling, thereby reducing operation of the refrigeration system. The temperature at which outdoor air cooling is advantageous may be even lower in large buildings with high velocity systems, since the power required for fan motors in these systems is higher. However, in buildings that have operable windows, night cooling – even at higher outdoor air temperatures – is worthwhile, as fan motors need not be operated.

If the dry-bulb temperature of the outdoor air is above indoor temperature, the wet-bulb temperature of the outdoor air can be higher than the room wet-bulb temperature. There may be periods when air at higher wet-bulb temperatures, introduced directly into spaces that have been cooled during the day, will cause condensation on walls or furnishings. Maintaining higher space temperature conditions (78°F and above) will minimize the amount of time condensation can occur and nearly eliminate the constraint in most geographic locations. Even in humid climatic zones, wet-bulb temperatures above 78°F occur for relatively few hours at night. The need to limit economizer operation exists only during those hours.

Where there are no automatic controls to operate an economizer cycle, dampers and fans should be operated manually, or controls installed.

To fully utilize outdoor air for cooling, it may be necessary to install return air and outdoor air dampers and provide a means of relieving air pressure. Some possible options include partially opening some windows, operating an exhaust system, or installing some propeller-type exhaust fans in the wall. Refer to Guidelines for Saving Energy in Existing Buildings (see references) for more details on economizer or enthalpy control.

During occupied periods, the opportunities to use outdoor air for cooling depend not only upon outdoor dry-bulb temperature, but also upon the wet-bulb temperature. If outdoor air is brought into the building above 66°F WB, the equivalent to the wet-bulb temperature is a measure of the total heat content of the air. If the wet-bulb temperature is lower than 66°F, outdoor air can be introduced through the cooling coil, with the refrigeration system in operation in any quantity. At less than 66°F WB, outdoor air will reduce the cooling load. However, for many existing systems (even when the temperature of outside air is less than 66°F WB), the cooling coils are not designed to handle outdoor air at temperatures above 85°F DB and still maintain room conditions at 78°F DB, despite the fact that outdoor air at less than 66°F WB actually has a lower total heat content than room air. Figure 1 indicates the number of wet-bulb degree hours below 66°F WB when the dry-bulb temperature is less than 85°F in the summer. If a building is located where there are 3000 or more such degree hours, an enthalpy controller is a good investment. On a seasonal basis, Denver, Colorado, has low wet-bulb temperatures, and it would be more economical to utilize 100% outdoor air through the air conditioning coils in the daytime, rather than to recirculate the air. However, summer outdoor dry-bulb temperatures in Denver often rise above 90°F. If the existing coils have not been selected to reduce the temperature of outdoor air at those times, they will be incapable of handling the conduction, solar, and internal heat gains that occur. To

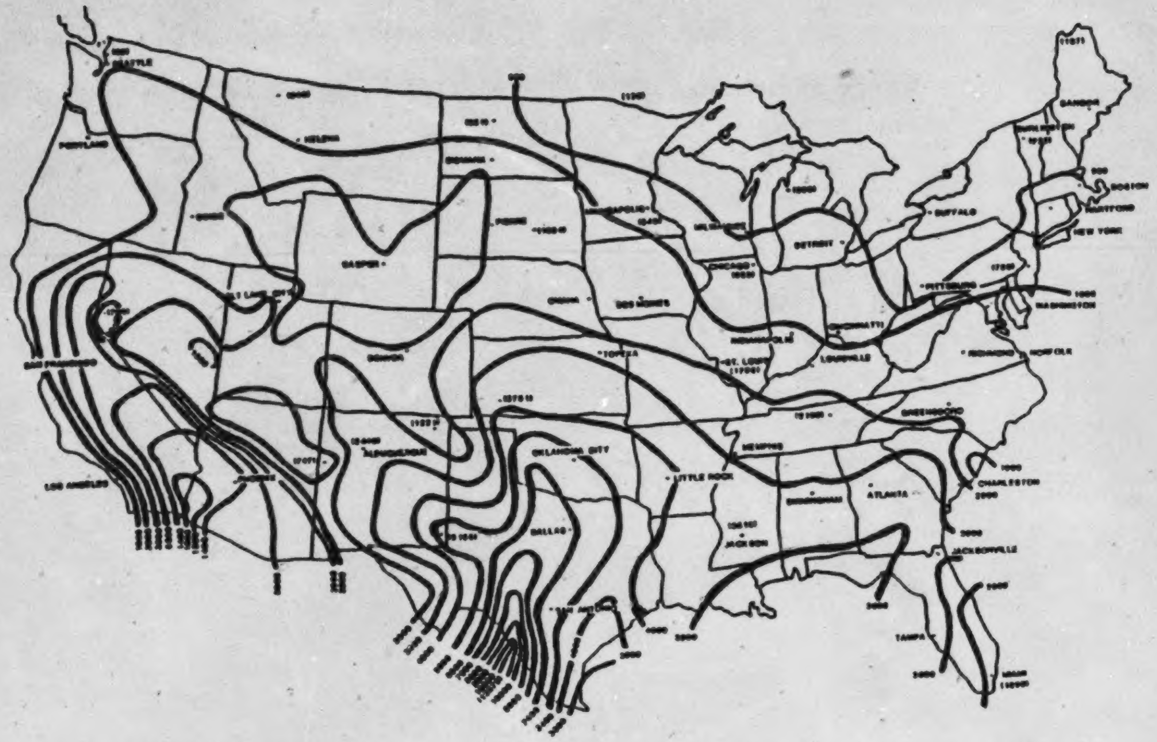

SEATTLE
PORTLAND
HELENA
BISMARCK
BOISE
CASPER
PIERRE
SALT LAKE CITY
SAN FRANCISCO
DENVER
LOS ANGELES
PHOENIX
ALBUQUERQUE
OKLAHOMA CITY
DALLAS
SAN ANTONIO
OMAHA
TOPEKA
DES MOINES
MILWAUKEE
CHICAGO
DETROIT
INDIANAPOLIS
CINCINNATI
ST. LOUIS
LOUISVILLE
BUFFALO
BANGOR
BOSTON
HARTFORD
NEW YORK
PITTSBURGH
WASHINGTON
RICHMOND
NORFOLK
GREENSBORO
MEMPHIS
LITTLE ROCK
BIRMINGHAM
ATLANTA
JACKSON
CHARLESTON
JACKSONVILLE
TAMPA
MIAMI

Figure 1. Annual Degree Hours Dry-Bulb Temperature Greater Than 85°F.

conserve energy in this climate, the outdoor air damper should be fully opened, except when indoor dry-bulb temperature cannot be maintained. Operating systems manually to reflect temporary conditions and conserve energy is sometimes difficult, but the effort yields significant savings. Automatic controls are available to optimize the operation of most systems and to meet varying and selective conditions.

Indoor temperature and relative humidity levels should be increased during occupied hours. (With terminal reheat systems in operation, the indoor space conditions should be maintained at lower levels to reduce the amount of reheat and save energy. If cooling energy is not required to reduce the temperatures, 74°F DB instead of 78°F should be maintained.)

The air conditioning systems in many buildings were designed to maintain 72° to 75°F DB and 50% RH during peak loads in the cooling season. Systems are operated to maintain those levels at peak conditions and to achieve even lower levels during the part-load conditions that occur most of the time.

Dry-bulb temperature and relative humidity for various spaces should be maintained at the levels suggested in Table 1 to reduce the cooling load and energy and operating costs. Even greater savings can be realized — without serious discomfort — by maintaining higher levels in areas that are occupied only for short periods of time. If unoccupied periods in these areas exceed 60% of the day, the cooling units should be turned OFF or registers, grilles, and diffusers closed. Temperature and humidity should be allowed to rise when the areas are unoccupied. (Auditoriums, corridors, cafeterias, and conference rooms are all spaces frequently unoccupied for most of the day.) Increasing the indoor temperature and humidity levels from 74° DB and 50% RH to 78° DB and 55% RH will save approximately 13% of the energy required for cooling. The exact amount depends upon the amount of ventilation air and infiltration that enters the building; the conduction losses, solar heat gain, and internal loads of the building; and the type of air conditioning system the building has. The multipliers in Table 2 can be used to determine the amount of energy saved (in Btus per hour) per 1000 cubic feet per minute (cfm) of outdoor air (ventilation plus infiltration) by raising the dry-bulb temperatures at constant relative humidities. (All other factors are considered constant. Since the effect of raising the dry-bulb temperature on conductive heat gain is actually negligible, it has been disregarded here.)

TABLE 2. SAVINGS ACHIEVED BY RAISING INDOOR DRY-BULB TEMPERATURE.*

Dry-Bulb Temperature	Relative Humidity		
	50%	60%	70%
72°F	0	0	0
73°F	2700	2433	3000
74°F	2657	2400	3257
75°F	3000	2572	3000
76°F	3000	2572	3000
77°F	3000	2572	3429
78°F	3000	2572	3429

*Savings are expressed in Btu/hr/1000 cfm.

GUIDELINES TO REDUCE ENERGY USED FOR COOLING

The following are guidelines to employ in reducing cooling energy.

1. Use outdoor air for cooling.

   - Use outdoor air for economizer cooling whenever the enthalpy is lower than room conditions during occupied periods, and whenever the dry-bulb temperature is 5°F lower than indoor design conditions during unoccupied periods. (If the dry-bulb temperature is only 2° lower than room temperature, heat from absorbed fan horsepower will eliminate the value of outdoor air cooling.)

   - Use operable windows, without fan operation, for outdoor air cooling. Outdoor temperature during unoccupied periods should be below room DB, and during occupied periods below room DB and WB conditions. (Unfavorable acoustics and air quality may preclude implementation of this option.)

- If cool outdoor air is available, consider cooling the building well below normal during the night and early morning hours preceding any day that is expected to be extremely hot.

- Whenever the volume of outdoor air is increased for economizer cooling, and if there is no exhaust system that can handle an equal quantity of air, provide pressure relief.

2. Reduce ventilation rate during the cooling season.

   - Refer to guidelines in Table 3 to reduce ventilation rates during the heating season.

TABLE 3. VENTILATION GUIDELINES.

Oxygen Supply	3 cfm/person
Cafeterias	10-12 cfm/person
Smoking Areas	25-40 cfm/person
Odor Control	5 cfm/person
Toilet Exhaust	10-15 air changes/hr
Corridors	2 air changes/hr

- When the enthalpy of the outdoor air (on a seasonal basis) is lower than room conditions, outdoor air dampers should be fully opened. Close them only at times when the enthalpy of the outdoor air is higher, or dry-bulb temperature of outdoor air is above 85°F.

- Check local and state codes to determine if ventilation rates can be legally lowered when spaces are air conditioned.

- Do not reduce ventilation rates when outdoor air can be used for economizer or enthalpy cooling.

3. Reduce infiltration rates during the cooling season.

   - Before investing any money to reduce infiltration rates, perform an analysis for both heating and cooling.

- Whenever infiltration rates are reduced for winter conditions, additional benefits accrue from reducing the cooling load in the summer.

- In areas of the country that experience fewer than 10,000 wet-bulb degree hours, energy conserved by weather stripping windows and doors and/or caulking window frames does not generally justify the cost. In climatic zones that experience a greater number of wet-bulb degree hours, make an engineering analysis of weather stripping and caulking to reduce cooling loads.

- The rate of infiltration in stores through door openings may be considerably higher than leakage through windows or cracks.

- Refer to Module EA-06 for additional guidelines.

4. Control solar heat gain.

- In hot weather, adjust existing blinds, drapes, shutters, or other shading devices on windows to prevent penetration of solar radiation into the building. (In the case of certain types of shading devices, this modification may conflict with requirements to utilize natural illumination; an engineering analysis of relative energy consumption due to solar radiation loads versus artificial illumination loads may be required.)

- Install blinds, drapes, shutters, or other shading devices on the inside of all south, east, and west facing windows that are subject to direct sunlight in hot weather and/or exposed to a large expanse of sky. (Fire codes may limit the use of some materials. Where dependent on natural light, do not reduce available light below statutory limits.)

- Use lightweight drapes that have reflective properties for effective solar radiation control. (Again, check fire codes before selecting appropriate material.)

- Use vertical or horizontal reflective blinds. (Vertical blinds or louvers generally are most effective on the west and east sides of a building; horizontal blinds are most effective on the south side.)

- Add reflective film coating to the inside surface of glazed areas on the south, west, and east windows. (Where dependent on natural light, refer to occupational regulations or health and safety codes before drastically reducing light.)

Note: Reflective mylar sheets (or rolls) and plexiglass sheets are available from many manufacuters at relatively low cost. Not only do they help control solar radiation, but they may also increase the strength and resistance of glazed areas. The thicker materials are good wind insulators – a 1/4-inch sheet of plexiglass is as good as a single pane of glass. Available in different colors, the films allow a maximum transmission of from 55 to 90 Btus/hr/sq ft, depending on quality and make. The maximum heat transmitted in Btu/hr/sq ft for a clear single pane of glass is 215 Btu/hr/sq ft. The films transmit 9 to 33 percent of the visible light spectrum and reflect 50 to 75 percent of the solar radiation that strikes them.

For example, reflective coating on the south, east, or west exposure glass that reduced solar radiation by 50 percent would save from 30,000 to 50,000 Btus/sq ft window per seaosn (in hot weather) in energy required for space cooling. (The value is higher in northern latitudes and lower in southern latitudes because of the angle of the sun striking vertical surfaces.) The cooling load can be reduced by about 3 ton hours/sq ft of glass per year by proper use of shading devices. In southern climates, the north facing glass can receive a surprising amount of diffuse solar radiation. If heat gain from north windows is excessive, treat them similarly to the other exposures.

- It is not cost-effective to add storm sash solely to reduce solar heat gain.

- Skylights on a roof transmit between two and four times as much solar heat in the summer as an equal area of east or west facing glass. Exterior solar control over skylights is most effective, and permits solar radiation and daylight to enter when desirable. Interior shades with mylar reflective coatings reduce solar heat gain in the summer by up to 80%. White paint on the exterior of skylights, venetian blinds, or sun screens can also be employed to reduce solar heat gain.

- Do not prune trees that shade the building in the summer.

5. Reduce internal heat gain.

   - Turn off unnecessary lights and heat-producing equipment.

   - Reduce lighting levels by removing lamps. See Module EA-05, "Lighting Systems."

   - Exhaust the heat from ovens, ranges, and motors directly outdoors when the enthalpy of the outdoor make-up air is lower than the enthalpy of the space.

   - Insulate hot surfaces of tanks, piping, and ducts that are in air conditioned spaces.

   - Disconnect dry-type transformers that are in conditioned spaces when there are no operating loads.

6. Reduce conductive heat gain through the building envelope.

   - In climates without a significant heating season, adding a storm sash or double glazing is not usually economically feasible.

   - Do not confuse solar radiation heat gains through windows with conductive gains. Solar radiation control cannot be neglected.

- Make an engineering and economic analysis before insulating walls or roofs, installing a roof spray, or treating exterior surfaces to increase emissivity.

- Insulate roofs, or ceilings below roofs, that have a U factor of greater than 0.15 to improve the U factor to 0.06. (The U factor indicates the rate at which heat flows through a specific material or a building section.)

7. Conserve energy by operation and maintenance.

a) Increase evaporator temperature.

- Raise supply air temperature.

- Raise chilled water temperature.

- Operate one of multiple compressors and chillers at full load, rather than two or more at part loads.

- Maintain full charge of refrigerant.

- Maintain evaporator heat exchange surfaces in clean condition.

- Maintain higher relative humidity levels in air conditioned space.

- See Module EA-06 for specific measures that will result in lower evaporator temperatures and for measures to re-schedule chilled water temperatures.

b) Reduce condensing temperatures.

- Clean all condenser shells and tubes.

- Clean all air-cooled condenser coils and fins on a regular basis with compressed air or steam jets.

- Remove obstructions to free airflow into cooling tower and fans.

- Direct cool exhaust air from the building into the air intake of air-cooled condensers or cooling towers.

- Under light load conditions, when the refrigeration load is small and the ambient wet-bulb temperature is likely to be low, the cooling performance of the tower will exceed the needs of the refrigeration machines. Under these conditions, the cooling tower fan or fans can be cycled ON and OFF to maintain a desired condenser water temperature, thus saving the horsepower required to drive the fans.

- Adjust airflow and water rates to air-cooled condensers and cooling towers to produce the lowest possible condensing temperature. Generally, the savings in refrigeration power will exceed any increase in added power for condenser fans or pumps.

- Use well water, if available, for condenser cooling.

- Shade cooling towers and air-cooled condensers from direct sunlight.

- Remove bacterial slime and algae from cooling towers.

- Institute and maintain a continuous water treatment program for cooling towers.

- At partial refrigeration loads, operate cooling towers as natural draft towers with cooling tower fans turned OFF.

- Clean and de-scale spray nozzles, and de-scale fill in cooling towers.

- It is often more effective to operate chillers at full load in the morning when outdoor wet-bulb temperatures are low, and low condensing water temperatures can be obtained from the cooling tower. Then, use the machine to subcool the building; turn the chiller OFF when wet-bulb temperatures rise and allow the building temperature to drift up. In large buildings, the extensive chilled water piping system provides a degree of thermal storage.

c) Improve the efficiency by improved maintenance practices.

- Repair refrigerant leaks.

- Lubricate speed-reducing gear boxes.

- Replace worn bearings.

- Maintain proper tension of V-belt drives.

- Adjust water flow control valves to maintain lower condensing temperatures.

- If well water is used for condenser cooling, provide proper treatment to prevent scale buildup.

- Clean and replace, as necessary, all strainers to reduce resistance to refrigerant or water flow.

- Select a water treatment system for cooling towers that allows high cycles of concentration (suggested target greater than 10.7) and reduces blow-down quantity.

- Maintain boiler and burner efficiencies where steam or hot water is generated for absorption cooling units. Refer to Module EA-06.

Many or most of the options listed can be implemented by the building maintenance staff. An alternative, however, would be to let a service contractor, with an inspection and labor-type service contract, service simple air conditioning and fan coil units on an annual fee basis, which includes costs of labor (for inspection, maintenance, breakdown repair) and material (such as filters, oil, grease, etc.). Typical cost consideration checkpoints and action for a service contractor might be the following:

- Refrigeration Equipment (Figure 2)

  Circuit and Controls: Inspect the moisture-liquid indicator on a regular basis. If the color of the refrigerant indicates "wet," there is moisture in the system. This is a particularly critical problem because it can cause improper operation or costly damage. A competent mechanic should be called in to perform necessary adjustments and repairs immediately.

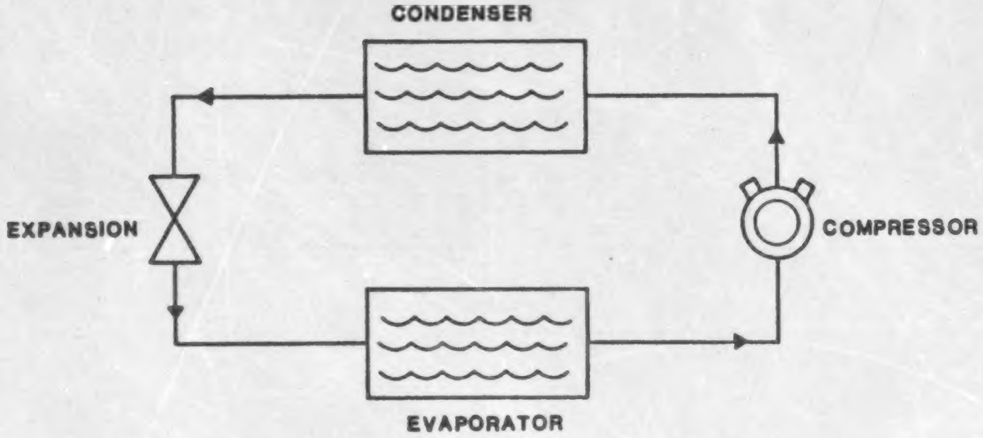


Figure 2. Refrigeration Diagram.

Also, bubbles in the refrigerant flow, as seen through the moisture-liquid indicator, may indicate that the system is low in refrigerant. Call in a mechanic to add refrigerant, if necessary, and to inspect equipment for possible refrigerant leakage.

Use a leak detector to check for refrigerant and oil leaks around the shaft seal, sight glasses, valve bonnets, flanges, flare connections, the relief valve on the condenser assembly, and at pipe joints to equipment, valves, and instrumentation.

Inspect the equipment for any visual changes, such as oil spots on connections or oil on the floor under the equipment.

Inspect the liquid line leaving the strainer. If it feels cooler than the liquid line entering the strainer, it is clogged. If it is badly clogged, sweat or frost may be visible at the strainer outlet. Clean as required.

Observe the noise made by the system. Any unusual sounds can indicate a problem. Determine the cause and correct the problem.

Establish normal operating pressures and temperatures for the system. Check all gauges frequently to ensure that design conditions are being met. Increased system pressure may be due to a dirty condenser, which will decrease system efficiency. High discharge temperatures often are caused by defective or broken compressor valves.

Inspect tension and alignment of all belts and adjust as necessary.

Where applicable, lubricate motor bearings and all moving parts according to the manufacturer's recommendations.

Inspect the insulation on suction and liquid lines. Repair as necessary.

Compressor: Look for unusual compressor operation, such as continuous running or frequent stopping and starting. Either may indicate inefficient operation. Determine the cause and, if necessary, correct the problem.

Observe the noise made by the compressor. Excessive noise may indicate a loose drive coupling or excessive vibration. Tighten the compressor and the motor on the base. If noise persists, call a competent mechanic.

Check all compressor joints for leakage. Seal as necessary.

Inspect the purge for air and water leaks. Seal as necessary.

Inspect instrumentation frequently to ensure that operating oil pressure and temperature agree with the manufacturer's specifications.

Air-Cooled Condenser: Keep the fan belt drive and motor properly aligned and lubricated.

Inspect the refrigeration piping connections to the condenser coil for tightness. Repair all leaks.

Keep the condenser coil clean to permit proper airflow.

Determine if hot air is being bypassed from the fan outlet to the coil inlet. If so, correct the problem.

Evaporative Condenser: Inspect piping joints and seal all leaks.

Remove all dirt from the coil surface by washing it down with high velocity water jets or a nylon brush.

Inspect the air inlet screen, spray nozzle or water distribution holes, and pump screen. Clean as necessary.

Use water treatment techniques if local water supply leaves surface deposits on the coil.

Follow the guidelines for fan and pump maintenance.

Water-Cooled Condenser: Clean the condenser shell and tubes by swabbing with a suitable brush and flushing out with clean water.

Chemical cleaning also is possible, although it is suggested that a water treatment company be consulted first.

Cooling Towers: Perform chemical analysis to determine if solid concentrations are being maintained at an acceptable level.

Check the overflow pipe clearance for proper operating water level.

Check the fan by listening for an unusual noise or vibration. Inspect the condition of the V-belt. Align the fan and motor as necessary.

Follow the guidelines for fan maintenance.

Keep the tower clean to minimize both air and water pressure drop.

Clean the intake strainer.

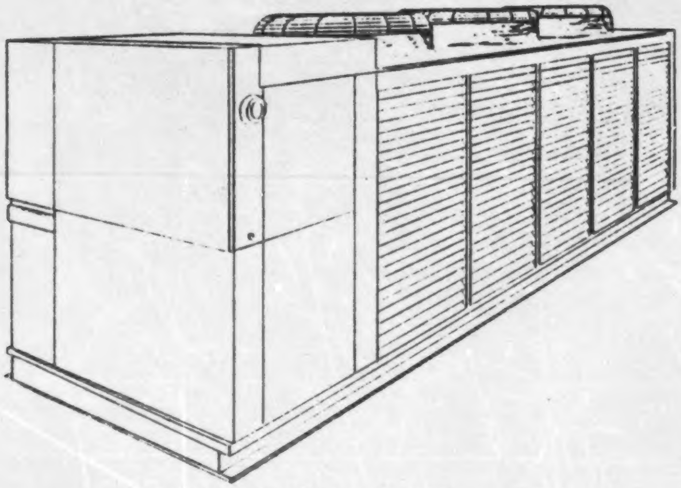
Determine if there is an air bypass from the tower outlet back to the inlet. If so, the bypass may be reduced through adding baffles or higher discharge stacks.

Inspect the spray-filled or distributed towers for proper nozzle performance. Clean the nozzles as necessary.

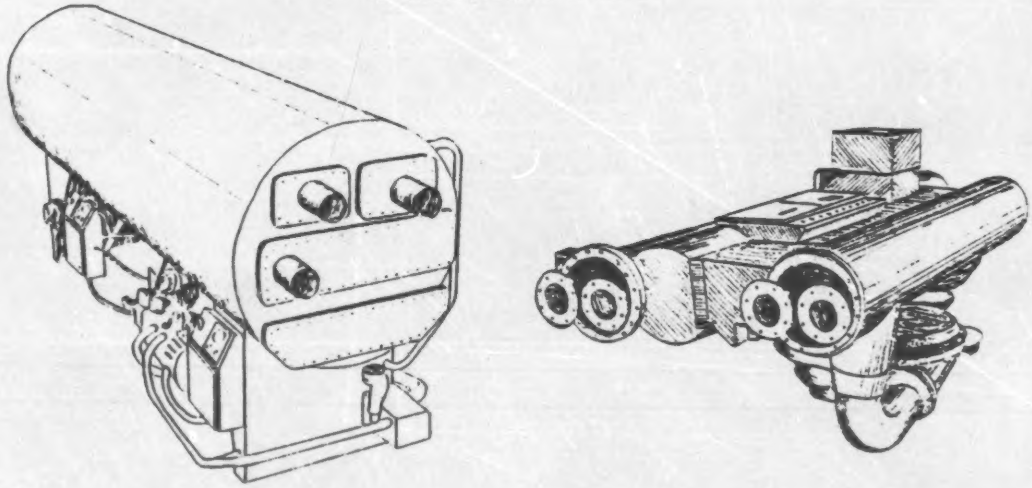
Inspect the gravity distributed tower for even water depth in distribution basins.

Monitor the effectiveness of any water treatment program that may be under way.

Chillers: (Figure 3)



a. RECIPROCATING CHILLER



b. ABSORPTION CHILLER

c. CENTRIFUGAL CHILLER

Figure 3. Types of Chillers.

Chillers must be kept clean. Inspect them on a regular basis. Clean the chillers as necessary.

Inspect for evidence of clogging. A qualified mechanic should be called in to service equipment in accordance with the manufacturer's specifications.

Absorption Equipment: Clean the strainer and seal tank on a regular basis.

Lubricate the flow valves on a regular basis.

Follow the manufacturer's instructions for proper maintenance.

Self-Contained Units (Windows and Through-the-Wall Units; Heat Pump, etc.): Clean the evaporator and condenser coils.

Keep the air intake louvers, filters, and controls clean.

Keep the airflow from units unrestricted.

Caulk the openings between unit and windows or wall frames.

Check voltage. Full-power voltage is essential for proper operation.

Follow applicable guidelines suggested for compressor, air-cooled condenser, and fans.

- HVAC Controls

The controls originally installed in many buildings were designed in light of initial costs rather than for their ability to conserve energy. In addition, just five years of use without adequate maintenance – which seldom is performed – can cause controls to go out of calibration, becoming even less sensitive. A program of control adjustment and modification should adhere to the following procedure:

Adjust the controls at the time of testing, including adjustment and balancing of all heating and cooling systems.

Check the operation of the entire heating/cooling control system, including control valves and dampers. Correct all improper operations.

Check the control system for instrument calibration and set point, actuator travel and action, and proper sequence of operation.

Inspect the location of thermostats. Relocate if thermostats currently are positioned near outside walls, in seldom used areas, or if subject to outside drafts.

Consider the installation of key-lock plastic covers over the thermostats to prevent building occupants from adjusting settings.

Consider replacing the pilots of gas-burning equipment with electric ignition devices.

- Ventilation Levels

  Air brought into a building for ventilation must be heated or cooled and often humidified or dehumidified. Ventilation systems account for an estimated 10 percent of a building's overall energy consumption, yet it is generally agreed that most building codes demand levels of ventilation in excess of what is actually needed to provide for the safety and comfort of building occupants.

  Building code ventilation standards should be examined to ensure that they are realistic in their appraisal of health and safety needs.

8. Consider the following when selecting a new heating, ventilating, and air conditioning system.

- Do not buy equipment with excess capacity. Most equipment works at maximum efficiency when running at full capacity. Most systems, however, are designed to meet extreme weather conditions, which seldom occur, resulting in inefficiency.

- Provide adequate zones of control. Without control zones, large areas often have to be overcooled or overheated to satisfy the needs of small areas. Thus, zoning reduces the HVAC load.

- Group areas with similar heating, cooling, and ventilation requirements to facilitate selective ventilation.

- Use waste heat. Until recently, the heat generated by a building's lights, machinery, and people was ignored. Rising energy prices, however, are stimulating interest in waste heat recovery systems, which can retrieve up to 80 percent of waste heat, creating a two-fold energy benefit: (a) waste heat can be used to supplement, and sometimes replace, expensive fuel-based heat; and (b) removal of waste heat eliminates an expensive burden on the air conditioning system.

Waste heat recovery systems are expensive, but usually pay for themselves quickly with energy savings. The Smithsonian Institution installed a heat recovery system that paid for itself in four months. An HVAC maintenance program should be initiated when the building is completed, based on guidelines outlined in this module.

- Consider an economizer cycle. An economizer cycle allows the air-handling equipment to utilize outdoor air during the winter season to cool the interior of the building. Two types of economizer cycles are enthalpy control and dry-bulb changeover temperatures.

EXERCISES

1. Determine the approximate yearly energy savings resulting from a reduction of air infiltration. It is necessary to determine how much air is being introduced into the building and the minimum quantity that may be introduced into the building legally. The difference determines the potential reduction of ventilation air and energy savings. For the cooling season, use Figure 4 to determine the energy required to cool and dehumidify a given amount of ventilation air.

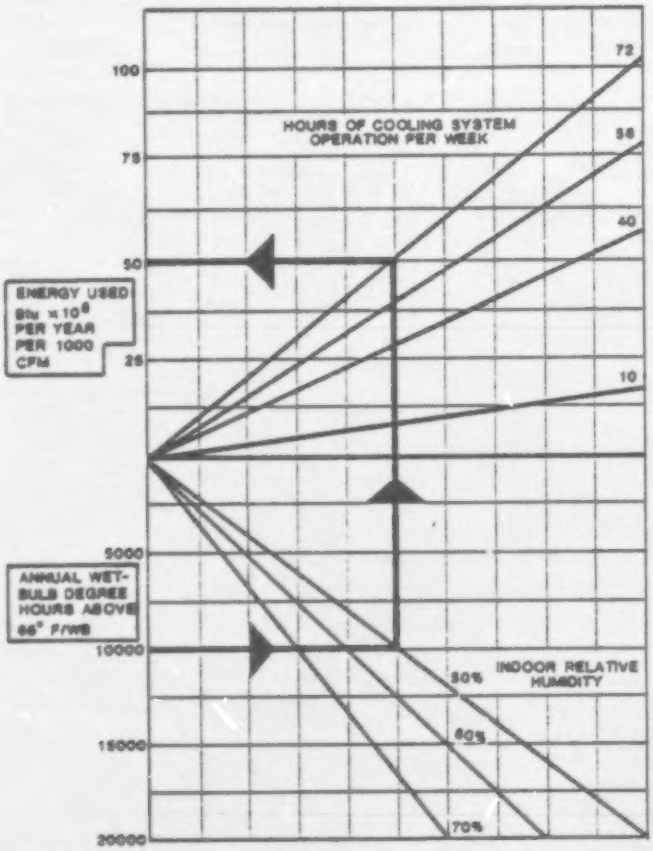


Figure 4. Cooling: Yearly Energy Used Per 1000 cfm to Maintain Various Humidity Levels.

For this exercise, use the following building profile and data.

Building Type	Office
Location	Miami, FL
Occupied Hours/Week	40
Number of Occupants	667
Indoor Relative Humidity	50%
Annual Wet-Bulb Degree Hours Above 66°F	18,500
Mechanical Refrigeration System, COP	2.5
Electricity Cost	$0.04/kWh
Btu/kWh	3,412

Determine energy saved by reducing outdoor air from 30 cfm/person to 8 cfm/person (mixed population of smokers and nonsmokers).

a. Determine total cfm reduction. Enter Figure 4 at 18,500 degree hours, intersecting with the 50% RH and 40-hour lines. Follow the example line and read yearly energy used of ______________.

b. Savings:

Total energy saved: ________________

Reduction of energy input due to COP: _________

Convert to kWh: ___________

Convert to cost: __________

2. Project the savings achieved in cooling outdoor air by raising the indoor dry-bulb temperature from 72°F to 78°F for the following building:

Type	Office, 40-hour occupancy
Annual WB Degree Hours Above 66°F WB	8,000
Total Outdoor Air Including Infiltration	10,000 cfm
Relative Humidity	50%

Use Table 2 to supply the following information:

a. Savings over total temperature change: ______.

b. For the outdoor air rate of this building, the savings will be __________.

c. For 40 hours of cooling per week and a cooling season of 20 weeks, yearly savings will be ______.

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Thumann, Albert. *Handbook of Energy Audits*. Atlanta: Fairmont Press, 1979.

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1. A ton of air conditioning capacity, in standard units of measure, is ...
   a. 19,000 Btu/hr.
   b. 13,000 Btu/hr.
   c. 12,000 Btu/hr.
   d. 10,000 Btu/hr.
2. If one kWh of electricity is required for a particular air conditioning unit to produce 2.7 tons of refrigeration, the unit's COP is ...
   a. 9.50.
   b. 8.75.
   c. 6.32.
   d. 10.90.
3. Determine the approximate annual energy savings resulting from a reduction of outdoor air from 20 cfm/person to 13 cfm/person in a building with the following characteristics, equipment, and energy data (see Figure 4):

Building Type	Institutional
Location	Dallas, TX
Occupancy	72 hrs/wk
Number of Occupants	1,091
Indoor Relative Humidity	50%
Annual Wet-Bulb Degree Hours Above 66°F	7,007
Absorption Cooling Equipment COP	68%
Cooling Power Supplied by Boiler, Seasonal Efficiency	65%
Btu/Gallon of Oil	138,000
Cost Per Gallon of Oil	$0.90

Choose the answers closest to your own. Use of charts may cause some deviation.

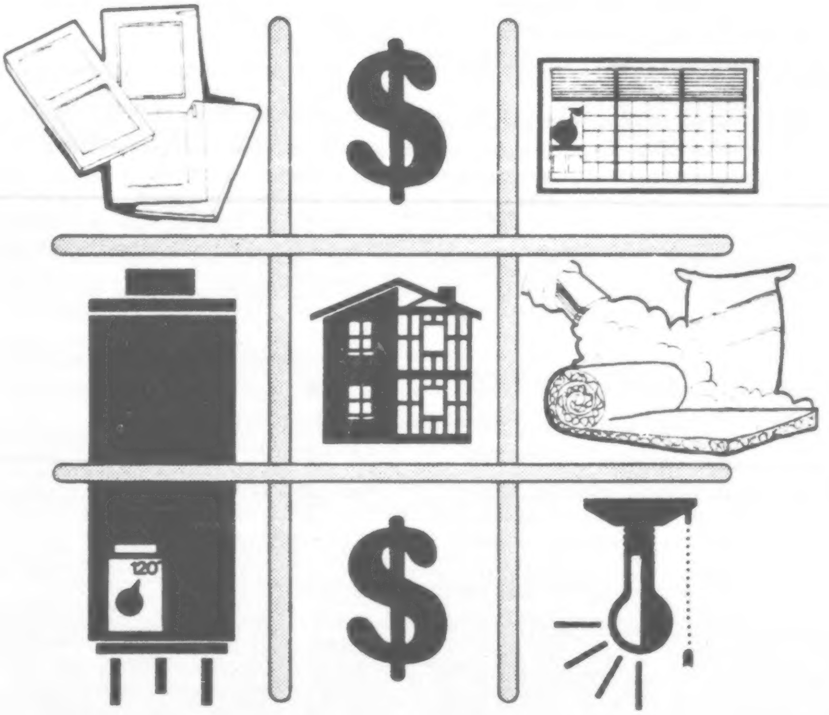
a. Total cfm reduction is ...
   (1) 9,739.
   (2) 7,637.
   (3) 5,737.
   (4) 6,376.
b. Annual energy consumption is ...
   (1) 17 x 10^6 Btu/1000 cfm.
   (2) 41 x 10^6 Btu/1000 cfm.
   (3) 27 x 10^6 Btu/1000 cfm.
   (4) 32 x 10^6 Btu/1000 cfm.
c. Total savings is ...
   (1) 244.4 x 10^6 Btu.
   (2) 291.3 x 10^6 Btu.
   (3) 198.2 x 10^6 Btu.
   (4) 214.3 x 10^6 Btu.
d. Reduction in efficiency due to cooling equipment is ...
   (1) 529 x 10^6.
   (2) 439 x 10^6.
   (3) 359 x 10^6.
   (4) 221 x 10^6.
e. Reduction in efficiency due to boiler is ...
   (1) 92,800.
   (2) 99,100.
   (3) 89,700.
   (4) 75,300.
f. Gallons of fuel saved per year is ...
   (1) 3,090.
   (2) 5,170.
   (3) 4,202
   (4) 4.002

g. Cost savings per year is ...
    (1) $3,601.80.
    (2) $4,106.20.
    (3) $2,131.70.
    (4) $3,998.90.

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY AUDITS



MODULE EA-08

AUXILIARY EQUIPMENT SYSTEMS

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

In addition to HVAC, lighting, and industrial process energy-using systems, buildings have numerous small energy-consuming systems and devices. When viewed individually, these smaller energy users — such as domestic hot water systems, appliances, and laundry facilities, among others — do not always appear to offer great energy conservation opportunities. However, when the auditor views them all together as an auxiliary equipment system, it becomes obvious that they contribute substantially to the building's total energy consumption. This module discusses the energy use characteristics of auxiliary system components and outlines the energy conservation opportunities with which the auditor should be familiar.

PREREQUISITES

The student should have completed Module EA-07, "HVAC Systems, Part II."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List components of typical auxiliary equipment systems.
2. Describe interactions between auxiliary equipment systems and total energy systems.
3. Calculate savings for operational conservation opportunities.

4. Calculate savings for maintenance conservation opportunities.
5. Calculate savings for retrofit conservation opportunities.

AUXILIARY FUNCTIONS

Every building has equipment and energy-using facilities that vary in type and importance with the specific function and construction of the building. Individually, these auxiliary functions may be as significant as a laundry facility in a hospital or as minor as a coffee pot in an office.

Regardless of the energy used by any single piece of equipment, the total energy used by all miscellaneous equipment is usually quite substantial. Much of the information needed to compute energy consumption will be found in the data on equipment nameplates.

This module discusses the energy use characteristics of (1) domestic hot water systems, (2) elevators and escalators, (3) kitchens and cafeterias, (4) laundries, (5) computer facilities, and (6) miscellaneous equipment, and details energy conservation opportunities appropriate to each. The auditor should always be aware of the fact that anything that consumes energy — in addition to building systems and the auxiliary equipment discussed in this module — also offers an energy conservation opportunity.

DOMESTIC HOT WATER

The term "domestic hot water" is used to distinguish the hot water used for "housekeeping" (in restrooms and kitchens) from the hot water used for heating and industrial processes. The amount of energy consumed in heating domestic hot water is about 4% of the annual energy used in most large commercial buildings. In smaller commercial buildings, the percentage is smaller. However, in facilities that include restaurants, cafeterias, and especially washaterias, the percentage of total energy used for hot water will be greater when compared to the amount of energy used by other systems. Domestic hot water systems offer much potential energy conservation. These energy conservation opportunities are discussed in detail in this module.

GENERAL CONSIDERATIONS

If domestic hot water is heated by the same boiler that heats the building, and if the load is only 10% or 20% of the total boiler load in those months when the building is heated, energy used in the fall and summer for domestic hot water may be higher than in winter. This is because, in this case, the boiler operates at low load efficiency.

The extensive opportunities to conserve energy for heating domestic hot water can be summarized as follows:

1. Reduce the load by decreasing the quantity and lowering the temperature of the domestic hot water.
2. Reduce system losses by repairing leaks and insulating pipes and tanks and by reducing recirculating pump operating time.
3. Increase the efficiency of the domestic hot water generator.

AVERAGE USE

Straight heat transfer calculations can be utilized to determine average hot water use rates in a particular building. This method is based on the assumption that the faucet is opened for a set amount of time, regardless of flow rate. For instance, washing hands is based on the time it takes rather than the water quantity. Table 1 shows average hot water use rates for typical commercial and institutional facilities.

TABLE 1. AVERAGE HOT WATER USE.

Office Buildings	
(Without kitchen or cafeteria services)	2 to 3 gallons per capita per day for hand washing and minor cleaning (based on an average permanent occupancy which includes daily visitors)
Department Stores	
(Without kitchen and cafeteria services)	1 gallon per customer per day
Kitchen and Cafeterias for Hand Washing	
Dishwashing, rinsing, and hand washing	3 gallons per meal plus 3 gallons per employee per day
Schools	
Boarding	25 gallons per capita per day
Day	3 gallons per capita per day (does not include cafeteria or athletic facilities)
Apartments	
High rental	30 gallons per capita per day
Low rental	20 gallons per capita per day
Hospitals	
Medical	30 gallons per capita per day
Surgical	50 gallons per capita per day
Maternity	50 gallons per capita per day
Mental	25 gallons per capita per day
Hotels	30 gallons per capita per day

AVERAGE TEMPERATURES

The temperature at which hot water is usually supplied (120°F to 150°F) is too hot to use directly and must be mixed with cold water at the tap. For dishwashing and sterilization, the delivery temperature is generally 160°F or higher. Often, hot water supplied to all faucets is at the temperature required for the kitchen. Frequently, the hot water, generated and stored in tanks at 150°F to 160°F, loses heat by conduction and radiation from the tank and piping even before delivery at wasteful temperatures. When hot water is supplied by a tankless heater, it is within 5°F to 6°F of the boiler water temperature maintained to heat the building. A mixing valve is often used to control the delivery temperature, but frequently the temperature at which it is set is excessive. If the tankless heater, or tank heater, is installed inside the boiler, the losses from the domestic heater may be considerable.

GENERATION AND STORAGE

Domestic hot water is generated (heated) and stored in one of the following ways:

- By a tankless heater from a hot water boiler used to heat the building, or by a below-the-water line tankless heater on a steam heating boiler
- By a tank heater and storage tank combination that is either a hot water or steam-heating boiler (The tank heater may be integral with the storage tank or separately mounted and connected to the boiler and tank by piping.)

- By a separate oil, gas, coal, or electric domestic hot water heater with integral storage tank
- By separate electric booster heaters without storage tanks

DISTRIBUTION

Hot water is distributed either by gravity circulation or by a recirculating hot water pump through separate piping to the fixtures. The recirculating hot water pump delivers hot water instantly at the faucets and reduces the total quantity of water used by saving the cold water that is usually drawn upon first opening the faucet. However, because the pump requires electrical power for operation, and because its piping system must always be filled with hot water (and, thus, experience heat loss), the use of the recirculating pump could be energy-wasteful in systems where all faucets are close to the tank.

ENERGY CONSERVATION OPPORTUNITIES

The following paragraphs outline energy conservation opportunities with which the energy auditor should be familiar.

DOMESTIC HOT WATER TEMPERATURES

Lowering the temperatures of the hot water reduces both the "building" domestic hot water load and the distribution load. The building load for water heating is expressed by Equation 1.

$$\text{Yearly Btus} = Q \times Td_B \qquad \text{Equation 1}$$

where:

Q = Quantity of domestic hot water used per year, in pounds.

Td_B = Magnitude of the difference in temperature between cold water entering the heater and hot water at the faucets, in °F.

Similarly, the parasitic load is determined by Equation 2.

$$\text{Yearly Btus} = Q \times Td_P \qquad \text{Equation 2}$$

where:

Q = Quantity of domestic hot water used per year, in pounds.

Td_P = Magnitude of difference between generation temperature and the temperature of water at the taps, in °F.

Therefore, Equation 3 is used to calculate total load.

$$\text{Yearly Btus} = (Q \times Td_B) + (Q \times Td_P) \qquad \text{Equation 3}$$

Since $Td = Td_B + Td_P$ (the difference between the temperature of water entering the heater and the generation temperature), Equation 3 can be restated as follows:

$$\text{Yearly Btus} = Q \times Td \qquad \text{Equation 4}$$

Figure 1 indicates energy used for domestic hot water at various generation temperatures and usage rates. An incoming water temperature of 50°F and 251 days of occupancy per year are assumed.

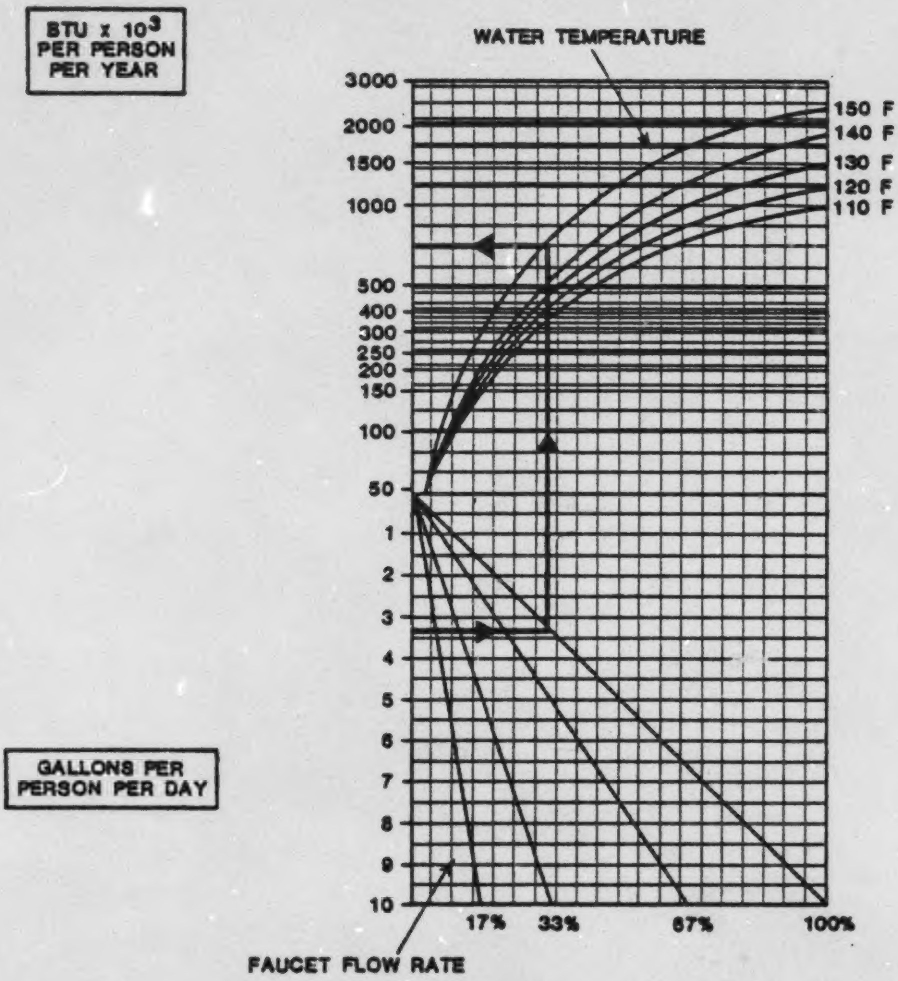


Figure 1. Hot Water: Savings from Reduction of Faucet Flow Rate and Water Temperature.

The actual amount of energy required to supply the total load depends upon the seasonal efficiency (E) of the heater, which varies with the type of heater and the fuel used. Table 2 shows the average efficiencies of typical heaters on a seasonal basis.

TABLE 2. AVERAGE WATER HEAT SEASONAL EFFICIENCIES.

Type of Heater	Average Efficiency
Oil-fired heating boilers used year round, but with domestic hot water as the only load	0.45
Oil-fired heating boilers used year round with absorption cooling in the summer	0.7
Gas-fired heating boilers used year round, but with domestic hot water as the only summer load	0.50
Gas-fired heating boilers used year round with absorption cooling in the summer	0.75
Separate oil-fired hot water heaters	0.70
Separate gas-fired hot water heaters	0.75
Separate electric water heaters	0.95
Separate coal-fired water heaters	0.45

To determine actual energy consumption, the value obtained from Figure 1 should be divided by the appropriate efficiency from Table 2. (If incoming temperature differs from 50°F, adjust value before dividing. If incoming temperature is 60°F, for instance, at a generation temperature of 150°F, multiply value by 150-60/150-50.) This is shown by Equation 5.

$$\text{Yearly Btus} = \frac{Q \times Td}{E} \qquad \text{Equation 5}$$

Example A shows the calculation of energy savings resulting from the reduction of domestic hot water temperatures at the faucets in a model office building.

EXAMPLE A: ENERGY SAVINGS RESULTING FROM THE REDUCTION OF THE TEMPERATURE OF HOT WATER SUPPLIED TO TAPS.

Given: An office building has 500 occupants, each of whom uses 3 gallons of hot water per day for 250 days each year. The temperature of the water as it enters the heater is 60°F (an average for the year), and it must be heated to 150°F in order to compensate for a 20°F drop during storage and distribution, and still be delivered, at the tap, at 130°F. Hot water is generated by an oil-fired heating boiler, used year round with domestic hot water as the only load. The fuel is #2 oil, which contains 138,000 Btus per gallon.

Example A. Continued.

Find:
(a) Building load
(b) Parasitic load
(c) Total load
(d) Total energy used
(e) Total fuel consumption
(f) Fuel needed at 90°F delivery temperature
(g) Fuel conserved

Solution: (a) Building Load:

Q = 500 occupants x 3 gal/day/occupant x 240 day/yr

Q = 375,000 gal/yr

1 gal = 8.3 lbs

Therefore,

Q = 375,000 gal/yr x 8.3 lbs/gal

Q = 3,112,500 lbs/yr

Td_B = 130°F - 60
= 70°F

Yearly Btus = 3,112,500 lbs x 70°F
= 217,875,000

(b) Parasitic Load:

Td_P = 150°F - 130°F
= 20°F

Yearly Btus = 3,112,500 lbs x 20°F
= 62,250,000

Example A. Continued.

(c) Total Load:

$$\text{Yearly Btus} = 217{,}875{,}000 + 62{,}250{,}000$$
$$= 280{,}125{,}000$$

(d) Total Energy Used:

$$E = 0.45$$

$$\text{Total Btus} = \frac{280{,}150{,}000}{0.45}$$
$$= 622{,}500{,}000$$

(e) Total Fuel Consumption:

$$\text{Yearly gallons} = \frac{622{,}500{,}000 \text{ Btus}}{138{,}000 \text{ Btu/gal}}$$
$$= 4{,}511$$

(f) Fuel Needed at 90°F Delivery Temperature:

$$4{,}511 \text{ gal} \times \frac{90°\text{F}}{130°\text{F}} = 3{,}123 \text{ gal}$$

(g) Fuel Conserved:

$$\underset{\text{(Item e)}}{4{,}511 \text{ gal}} - \underset{\text{(Item f)}}{3{,}123 \text{ gal}} = 1{,}388 \text{ gal conserved}$$

(This is actually a conservative figure, as the total savings in heating, storing, and distributing the water would include reduced storage and distribution losses as well.)

Table 3 indicates the yearly energy loss in Btus for various sizes of tanks (located in a space with an ambient temperature of 65°F) with fiberglass insulation.

TABLE 3. ANNUAL ENERGY LOSS FROM HOT WATER STORAGE TANKS (Btus in Millions/Year).

Insulation Thickness (in)	Tank Size (gal)	Energy Loss		
		Hot Water Temperatures		
		100°F	120°F	160°F
1	50	1.9	3.0	5.2
	100	3.0	4.7	8.2
2	250	3.1	4.9	8.4
3	500	3.1	4.9	8.4
	1,000	5.2	8.2	14.1

HOT WATER CONSUMPTION

Considerable energy savings can be realized by reducing the quantity of hot water used. Primarily, this energy conservation measure is beneficial in that energy consumption will be decreased to the same extent as with an equal percentage reduction in temperature.

A secondary benefit is the reduction in raw source energy that occurs because less water needs to be treated in the water supply treatment and sewage treatment plants – whether on-site or off-site. For municipal facilities, the diminished energy requirements will result in lower operating costs than otherwise possible, which in turn will mean that less taxes will be needed to support the facility. In areas where there is a charge based on total water consumption flowing into the sewer, the reduction in consumption of water will result in direct savings, as well. Water consumption can usually be lowered to 1-1/4 or 1-1/2 gallons per person per day in office buildings without inconvenience to the occupants.

Example B shows the procedure for calculating energy saved by reducing the quantity of hot water used.

EXAMPLE B: ENERGY SAVINGS RESULTING FROM A REDUCTION OF THE QUANTITY OF HOT WATER USED.

Given: An office building has 500 occupants, each of whom uses 3.5 gallons of hot water per day for 250 days each year. The water, as it enters the heater, is at 40°F, and it is heated to 150°F. The separate gas-fired heater has an efficiency of 0.75.

Find:
(a) Yearly energy used — 100% flow rate
(b) Yearly energy used — 33% flow rate
(c) Savings, in gallons of fuel (138,000 Btu/gal)
(d) Cost savings (fuel cost = $0.95/gal)

Solution:
(a) Enter Figure 1 at 3.5 gal/person/day. Follow the example line intersecting with the 100% flow rate and 150°F temperature lines, and read yearly energy used of 800 x 10^3 Btu/person/yr.

(b) Re-enter Figure 1, intersecting with the 33% and 120°F lines, and read yearly energy used of 190 x 10^3 Btu/person/yr.

Example B. Continued.

(c) The energy saved equals 800-190, or 610×10^3 Btu/person/yr. For 500 people, the total is $500 \times 610 \times 10^3$, or 305×10^6 Btu/yr.

$$\frac{305 \times 10^6}{138{,}000} \times 0.75 = 2{,}947 \text{ gal.}$$

(d) At $0.95/gal, the savings is 0.95 x 2,947, or $2,799.65/yr.

STORAGE AND DISTRIBUTION SYSTEMS EFFICIENCY

To reduce heat loss, all torn insulation should be repaired or replaced. Methods to improve the efficiency of both space heating and domestic hot water heaters and to reduce heat loss from piping are detailed in Modules EA-06 and EA-07.

One of the most effective ways to reduce heat loss from domestic hot water systems is to insulate both the piping and the tank.

Piping Insulation

Heat loss from uninsulated hot water system distribution piping can be substantial. The magnitude of these losses depends on the temperature differential between pipe and ambient air, pipe size, and length of system piping.

Exposed piping in basements and equipment rooms is relatively simple to insulate. Piping in ceiling spaces can also be made readily accessible by removing ceiling panels. Preferably, the entire piping system should be insulated, but inaccessible portions may be left bare, providing that they are a small percentage of the total.

Cost of installation varies in each building and should be estimated by an insulation contractor.

For costing purposes, add to total lineal feet of piping three (3) lineal feet for each fitting or pair of flanges to be insulated.

Savings achieved by insulating hot water piping are determined from Figure 2 for domestic hot water temperatures ranging from 100° to 180°. Example C demonstrates the use of Figure 2 in determining heat loss.

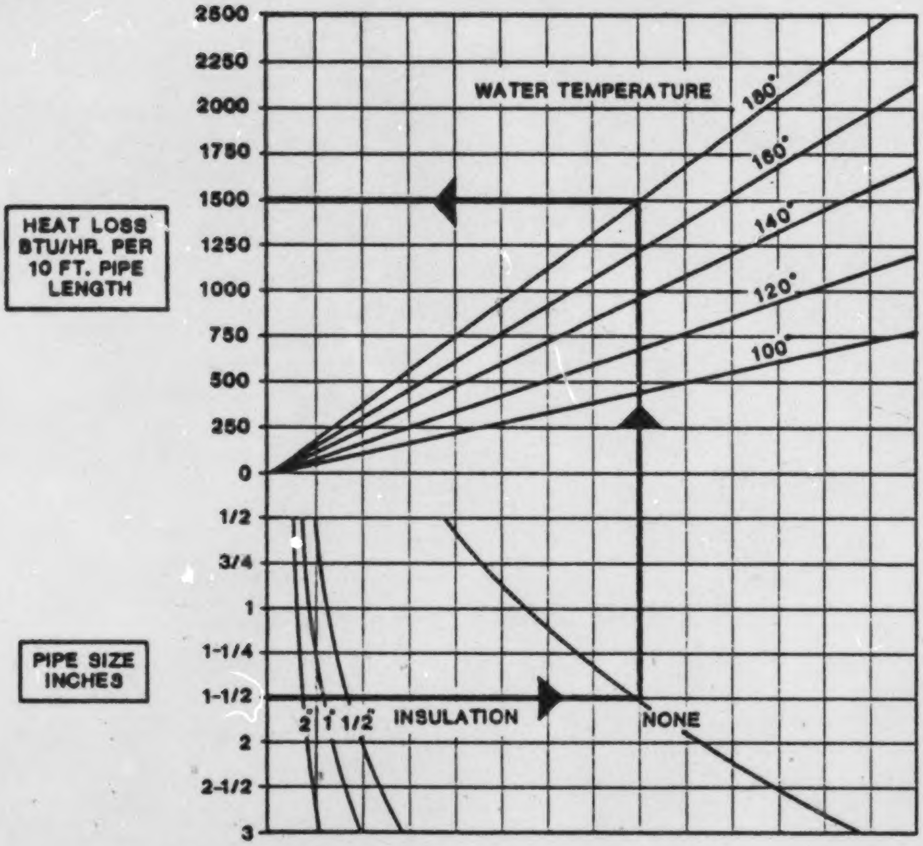


Figure 2. Heat Loss for Various Pipe Sizes, Insulation Thicknesses, and Water Temperatures.

EXAMPLE C: HEAT LOSS BY PIPE SIZE, INSULATION THICKNESS, AND WATER TEMPERATURE.

Given: System temperature: 160°F
Piping run lengths: 2-1/2 in – 125 ft
1-1/2 in – 30 ft
1-1/4 in – 350 ft
1 in – 150 ft
Present insulation: none

Find: Heat loss.

Solution: Enter Figure 2 at each pipe size, intersecting with curves labeled "none" and 160°F, and reading the heat loss in Btu per hour per 10 ft pipe length. Multiply these quantities by the respective lengths of each size pipe, giving a total system heat loss of 72,175 Btu/hr. The hot water system is operating 8,760 hours per year.

$$\text{Total yearly heat loss} = 8{,}760 \times 72{,}175 = 632 \times 10^6 \text{ Btu}$$

Example D demonstrates the methodology for using Figure 2 to calculate energy savings resulting from pipe insulation.

EXAMPLE D: ENERGY SAVINGS RESULTING FROM ADDING PIPE INSULATION.

Given: Water heating system data from Example C
Insulation added to all pipes: 1 inch
Heater data: oil-fired, 70% efficiency
Btu/gallon of oil: 138,000
Oil cost: $0.95/gal

Find: (a) Heat loss with insulation
(b) Savings, as compared with Example C

Solution: (a) Use Figure 2. Intersect with the lines for 1-inch insulation and 160°F line temperature for each pipe size.

$$\text{Total yearly heat loss} = 94.4 \times 10^6 \text{ Btu}$$

(b) Btu savings (difference in heat loss of uninsulated and insulated pipes):

$$(632 \times 10^6) - (94.4 \times 10^6) = 537.6 \times 10^6 \text{ Btu/yr}$$

$$\text{Oil savings} = \frac{537.6 \times 10^6}{138{,}000 \times 0.70}$$
$$= 5.5652 \times 10^3$$
$$= 5{,}565 \text{ gal}$$

$$\text{Cost savings} = 5{,}565 \text{ gal} \times \$0.95/\text{gal}$$
$$= \$5{,}286.75/\text{yr}$$

302

Insulation of Hot Water Storage Tanks

Heat loss from the domestic storage tank must continuously be offset by the addition of heat in order to maintain a ready supply of hot water. This heat loss occurs 24 hours per day, whether the building is occupied or not.

Storage tanks should be covered with a minimum of 3 inches of insulation. Bare tanks should also be insulated. Additional insulation should be applied to any tanks having less than 3 inches of insulation. All missing or torn insulation should be replaced or repaired.

Applicable codes should be checked to determine acceptability of various insulation materials.

Energy savings are calculated by determining the heat lost from the tank before and after insulation. Water temperature and ambient air temperature can be assumed to be constant. Savings in Btu per hour are multiplied by 8,760 (hours per year) to obtain the total yearly energy savings due to insulation.

HOT WATER GENERATION

All measures for improving combustion units for space heating apply equally well to hot water heaters. The auditor should keep in mind, however, that when more than one heater – be it boiler or hot water heater – is installed on a project, it is more efficient to operate one unit for the total load (if possible) rather than to operate all boilers at partial loads.

The greater opportunities for conserving energy by improving the efficiency of the hot water generators (after normal service operations and minor modifications have improved the existing equipment to the extent possible) will require major modifications or the replacement of equipment. The following hot water generation system modifications are the most frequently-made efficiency improvements, which entail significant expense.

- Replacing the central system with local heating units: Commercial hot water systems frequently require hot water for short periods of heavy use at various locations within the building. It is often more efficient to provide water heaters close to the usage points rather than central generation and long runs of hot water piping.

  The hot water use within the building should be analyzed to determine the patterns of demand and to determine whether installation of local units is advantageous. Energy losses of the existing system should be estimated as a basis for calculating the savings derived by installing local units. The energy saved is the sum of reduced distribution losses and the increase in the average generation efficiency of local units as compared to the existing central system.

  Before installing local hot water generation units, applicable codes should be reviewed to see if there are any restrictions on their locations or on the required modifications to the building, such as fire walls around fuel burning equipment.

- Installation of temperature boosters: When multiple temperature requirements are met by a central domestic hot water system, the minimum generation temperature is determined by the maximum usage temperature. Lower temperatures are attained by mixing with cold water at the tap. Where the majority of hot water usage is at the lower temperatures and higher temperatures are required at a few specific locations only, booster heaters or separate heaters for high temperatures should be installed.

- Installation of a separate boiler for summer domestic hot water generation: In many buildings, the heating system boilers provide primary heat for the domestic hot water system. While this is satisfactory during the heating season when the boiler is firing at high efficiency, demand for boiler heat in summer will probably be limited to hot water generation only. Operating large heating boilers at light loads to provide domestic hot water results in low boiler efficiency.

To reduce energy losses due to low boiler efficiency in summer, a separate hot water heater or boiler, sized for the hot water demand, should be installed. To generate hot water at improved efficiency, the heating boiler should be shut down in the summer.

To determine the cost of this modification, quotations should be obtained from a local contractor.

To determine the energy savings, the system's operating characteristics must be analyzed. Items investigated should include operating efficiencies of existing equipment during warm and cold months and hot water demand relationship to boiler capacity. Savings can be calculated by comparing the operating costs of both arrangements.

- Installation of a hot gas heat exchanger: A typical refrigeration machine with a water-cooled condenser rejects approximately 15,000 Btu/hour for each 12,000 Btu/hour of refrigeration. An air-cooled condenser rejects up to 17,000 Btu/hour. Up to 5,000 Btu/hour of the heat rejected from either system can be recaptured. To recover heat of compression, a heat exchanger may be installed in the hot gas line between the compressor and condenser of the chiller. A typical arrangement in conjunction with a domestic hot water system is shown in Figure 3. Hot gas temperature depends on head pressure, but is usually in the order of 120°F to 130°F.

  Cold water is circulated through the heat exchanger by the circulating pump. When hot water is not being used, water is pumped back through the heat exchanger, through the recirculating line. When hot water is needed, it is fed from either the heat exchanger, the hot water heater, or both. A mixing valve is provided to maintain the desired temperature.

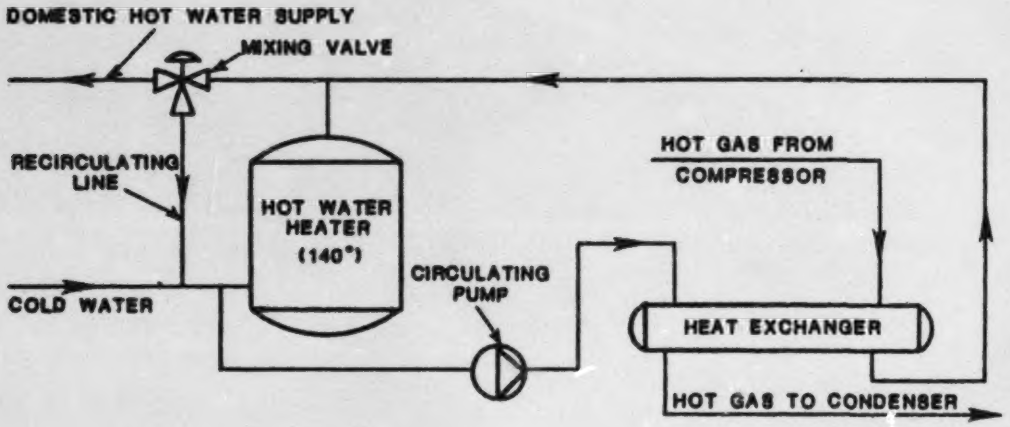

DOMESTIC HOT WATER SUPPLY
MIXING VALVE
RECIRCULATING LINE
HOT WATER HEATER (140°)
HOT GAS FROM COMPRESSOR
CIRCULATING PUMP
COLD WATER
HEAT EXCHANGER
HOT GAS TO CONDENSER

Figure 3. Heat Exchanger.

- Installation of a hot drain heat exchanger: Buildings with kitchens, laundries, and other service facilities that utilize large quantities of hot water, in many cases, discharge hot waste water to drains. By installing a heat exchanger, heat can be recaptured for use to preheat domestic hot water. (See Figure 4.)

  In general, it is economical to preheat water from 50°F to 105°F without excessive equipment cost. The hot water at 105°F can then be fed into the domestic hot water tank for further heating to utilization temperature, if required. The heat reclamation system saves the heat required to heat water from 50°F to 105°F which otherwise would have been provided by other heat sources.

- Installation of a hot condensate heat exchanger: The condensate return portion of many steam systems exhausts large quantities of heat in the form of flash steam when the hot condensate is reduced to atmospheric pressure in the condensate receiver. Heat waste can be recovered with the installation of a heat exchanger in the condensate return main, ahead of the receiver, to reduce condensate temperature to approximately 180°F. The heat recovered can be used to preheat water as required. Figure 5 is a schematic illustration of a hot condensate heat exchanger.

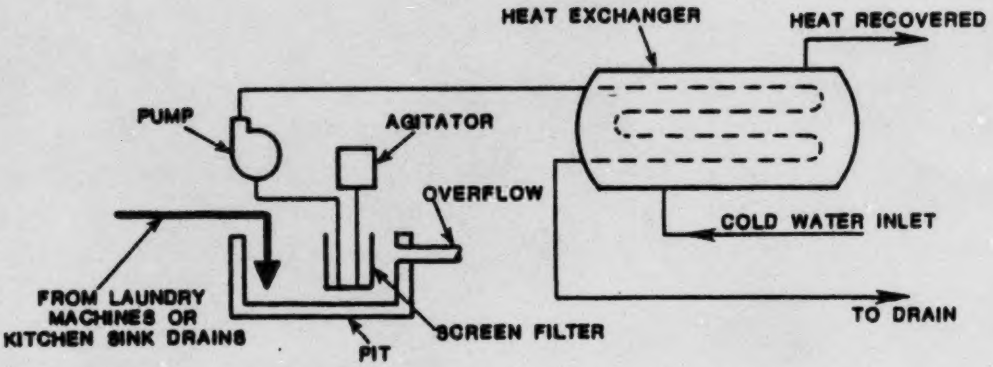

HEAT EXCHANGER
HEAT RECOVERED
PUMP
AGITATOR
OVERFLOW
COLD WATER INLET
FROM LAUNDRY MACHINES OR KITCHEN SINK DRAINS
PIT
SCREEN FILTER
TO DRAIN

Figure 4. Schematic of Laundry and Kitchen Hot Water Heat Recovery System.

The quantity of heat recovered depends on the pressure and temperature characteristics of the boiler. For example:

Steam has a condensate return volume of 6 gal/min at 260°F. A heat exchanger is installed to reduce the condensate temperature from 260°F to 180°F and the quantity of heat recovered is 240 x 10^3 Btu/hour. The average heat input required for the generation of domestic hot water is 1.1 x 10^6 Btu/day. In this instance, the entire domestic hot water load can be met for most of the year by the heat recovered in the hot condensate heat exchanger.

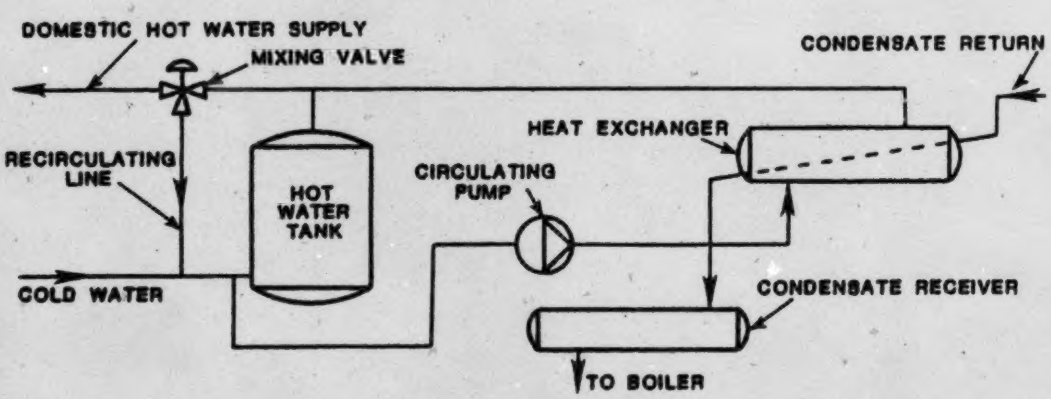

DOMESTIC HOT WATER SUPPLY
MIXING VALVE
CONDENSATE RETURN
HEAT EXCHANGER
RECIRCULATING LINE
HOT WATER TANK
CIRCULATING PUMP
COLD WATER
CONDENSATE RECEIVER
TO BOILER

Figure 5. Hot Condensate Heat Recovery System.

ELEVATORS AND ESCALATORS

Despite the fact that escalators draw relatively little current under no-load operation, it generally is recognized that their continuous action does tend to waste energy. Although intermittent, as-needed operation can be obtained through use of a treadle-type switch, relatively few such installations have been made due to safety concerns. When an escalator is shut down, however, it still provides a means of transportation – stationary stairs. By contrast, an elevator cannot serve any useful purpose when it is nonoperational. When elevators are running, however, they tend to be more efficient than escalators, although they cause indirect energy consumption due to stack effects created by the shaft and infiltration around cabs.

Following are a few of the options that should be considered in an effort to provide the elevator/escalator service required while conserving energy in the process.

1. Encourage building occupants (and perhaps visitors) to use the stairway when only one or two stories are involved and when security permits.
2. Perform a traffic review to determine if the building is properly elevatored, or over- or under-elevatored in regard to use during different periods of the day. If properly elevatored or over-elevatored, take one or more elevators out of operation at least during periods of light traffic.
3. If the building has automatic load-shedding or demand-limiting equipment, connect elevators to the system to enable automatic shut-down of one or more elevators to limit peak demand.

ELEVATORS

Elevators and escalators account for about 1%-4% of the electrical energy of office buildings and large department stores. The amount of power required annually to operate an elevator is based on the height of the building, the number of stops, passenger capacity and load factors, and the efficiency of the hoisting mechanism. For example, a 2,500-lb capacity "local" elevator making 150 stops per car-mile consumes about 5 kWh per car-mile, while an "express" elevator making 75 stops per car-mile consumes about 4 kWh. A 4,500-lb capacity elevator stopping at every floor in a 12-story department store will use 13 kWh per car-mile. Consumption varies between elevators of the same capacity, depending on the type of hoisting motor and control, the type of elevator and the kind of service, and the amount of load offset by the counterweight. The slowest speeds possible that will keep waiting times to a maximum of 2 minutes should be selected. A manufacturer or engineer should be retained to study the traffic patterns and to reschedule as necessary. Where multiple elevators are installed, the number in service during light traffic periods should be reduced.

The choice of new elevators – replacements or additions – should be made on the basis of the most efficient type for the application. The three major types of elevators are hydraulic, geared, and gearless. The limitations of each must be considered in evaluating its efficiency. Hydraulic elevators are used for speeds of about 200 ft/min, geared elevators for about 300 ft/min, and gearless elevators for higher speeds and high-rise buildings. Electric elevators with counterweights use less energy than hydraulic elevators.

ESCALATORS

Assuming 35% equivalent full load operation, escalator energy consumption may vary from 1.3 kWh for a 32-inch wide model operating at 90 ft/min with a 14-foot vertical rise, to 3 kWh for a 48-inch wide model operating at 90 ft/min with a 25-foot vertical rise. Escalators consume energy whether they are carrying passengers or not, as long as they are running.

KITCHENS AND CAFETERIAS

A variety of steps can be taken (at minimal expense) to effect more efficient energy use in kitchen, cafeteria, and other food-handling areas.

- Turn OFF infrared food warmers when no food is being warmed.
- Inspect refrigeration condensers routinely to ensure that they have sufficient air circulation and that dust is cleaned off coils.
- Inspect and repair walk-in or reach-in refrigerated area doors without automatic closers or tight gaskets.
- Train employees in conservation of hot water. Supervise their performance and provide additional instruction and supervision as necessary.
- Avoid using fresh hot or warm water for dish scraping.
- Keep refrigeration coils free of frost build-up.
- Clean and maintain refrigeration on water chillers and cold drink dispensers.
- Reduce temperature or turn OFF frying tables and coffee urns during off-peak periods.

- Preheat ovens only for baked goods. Discourage chefs from preheating any sooner than necessary.
- Run the dishwasher only when it is full.
- Cook with lids in place on pots and kettles. This will cut heat requirements in half.
- Thaw frozen foods in refrigerated compartments.
- Fans that cool workers should be directed so they do not cool cooking equipment.
- Consider using microwave ovens for thawing and fast-food preparation whenever they can serve to reduce power requirements.

One major energy conservation opportunity found in most food preparation facilities is the use of a separate make-up air supply for exhaust hoods. This can substantially reduce infiltration of outdoor air.

Kitchen equipment exhaust hoods and other process equipment hoods frequently remove large quantities of hot air from the building air, which must be made up by introducing outdoor air.

This make-up air is often introduced through the building HVAC system, which heats it in winter and cools and dehumidifies it in summer to the level required to maintain occupant comfort conditions within the building.

It is not necessary for the make-up air to be treated to the same degree as the air required by occupants. To conserve energy, a separate supply of make-up air for hoods should be considered. This make-up supply system may consist of a fan drawing in outdoor air and passing it through a heating coil in order to temper the air and maintain tolerable conditions immediately adjacent to the hood.

The temperature of the make-up supply air often need only be 50° to 55°, providing it is introduced close to, or around, the perimeter of the exhaust hood. This relatively low temperature air will not cause discomfort to an occupant in the immediate area, since the equipment radiates large quantities of heat that offset any cooling effect.

The effectiveness of an exhaust hood in capturing heated air, fumes, smoke, steam, and so forth, is a function of the face velocity at the edge of the hood. Large open hoods require large volumes of air to maintain a satisfactory capture velocity. Face or capture velocities can be maintained or even increased while decreasing the total quantity of exhaust air by fitting baffles or a false hood inside an existing open hood (Figure 6).

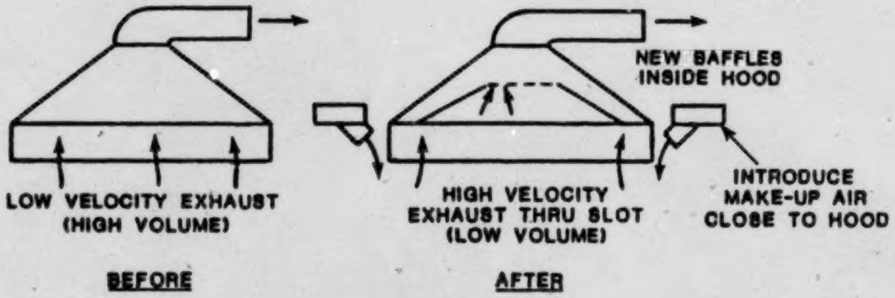

NEW BAFFLES INSIDE HOOD
LOW VELOCITY EXHAUST (HIGH VOLUME)
HIGH VELOCITY EXHAUST THRU SLOT (LOW VOLUME)
INTRODUCE MAKE-UP AIR CLOSE TO HOOD
BEFORE
AFTER

Figure 6. Increasing Exhaust Hood Capture Velocity.

The cost of modifying exhaust hoods and installing a separate make-up air system varies with the circumstances of each application. To make an accurate assessment, quotations should be obtained from local contractors based on engineering designs to meet the particular case.

LAUNDRIES

In addition to large commercial and industrial laundries, hospitals and public care institutions commonly have laundry facilities. Key energy conservation opportunities to look for in laundries include the following:

1. Potential reuse of waste heat from steam lines and drains.
2. Hours of operation. (Could operation hours be changed to limit demand peaks or eliminate the need for operating extra boilers or air conditioners?)
3. Days of operation. (Must the facility operate as many days per week?)
4. Eliminate extra load from high temperatures and humidity on the central or other area air conditioning systems.

COMPUTER FACILITIES

Recent research shows that buildings with substantial computer installations – in addition to data terminals – frequently consume significantly more energy than buildings without such installations. While energy consumption of the computer equipment is partly responsible, researchers feel that the primary cause is the extent to which the computer support facilities and equipment are in use. Typically, computer operations extend into periods when a building would otherwise be unoccupied – evening, late evening, early morning, weekends, and so forth. In some cases, computer operations continue around-the-clock. As a result, the building systems required to support computer equipment and personnel – HVAC, lighting, food service, elevator, and other systems – also must be operational and, thus, consume energy. Given the extensive amount of work performed by computers and those who run them, as well as their high rate of productivity, suggestions that their use be reduced to conserve energy would be out of the question. Nonetheless, there are steps that can be taken to ensure that no more energy than necessary is used to support computer operations. One logical solution is proper zoning of HVAC and lighting systems to isolate the areas.

MISCELLANEOUS EQUIPMENT

If the energy consumption of smaller, "incidental" equipment – such as coffee pots, typewriters, calculators, radios, electric space heaters, and so forth – is added up, the total usage may be surprising. (A large coffee maker may require up to 5,000 watts, for example.)

A building-wide awareness program should be established to minimize unnecessary use of all equipment. In particular, the program should emphasize that all equipment of this type be turned OFF overnight and during lunch periods.

1. Compare and contrast the two methods of hot water distribution.
2. Calculate the building domestic hot water load if there are 192,000 pounds of hot water used annually and the difference between the temperature of water entering the heater and water at the faucets is 100°F.
3. Using Figure 2, calculate the heat loss for a piping system of the following specifications:

   System temperature: 140°F

   Piping run lengths: 2-1/2 in – 200 ft
   1-1/2 in – 120 ft
   1-1/4 in – 190 ft
   1 in – 30 ft

   Present insulation: none

   Annual operation time: 8,760 hours

4. Using the data in Exercise 3, calculate the energy savings resulting from adding 1-inch insulation to all pipes.

   Heater data: oil-fired, 60% efficiency

   Fuel data: 138,000 Btu/gal

5. Explain the operation of a hot gas heat exchanger.
6. Explain the operation of a hot drain heat exchanger.
7. Discuss the relationship of make-up air to vent hood operation, and explain the appropriate energy conservation measure.
8. Design a brief program for reducing the amount of energy consumed by the miscellaneous equipment in a typical office building.

REFERENCES

American Gas Association. Maintenance Tips That Will Help Conserve Energy and Improve Your Food Service Operation. Cat. #R01023.

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Instructions for Energy Auditors, Vol. I. Springfield, VA: NTIS, Sept. 1978. (DOE/CS-0041/12.)

Instructions for Energy Auditors, Vol. II. Springfield, VA: NTIS, Sept. 1978. (DOE/CS-0041/13.)

Texas Energy Auditor Training Manual, 1980. Austin: Texas Energy and Natural Resources Advisory Council, 1980.

Thumann, Albert. Handbook for Energy Auditors. Atlanta: The Fairmount Press, 1979.

Choose the answer closest to the correct one for each question. Questions 1-7 refer to Case A; Questions 8-11 refer to Case B.

CASE A: AN OFFICE BUILDING WITH 225 OCCUPANTS, EACH OF WHOM USES 2.5 GALLONS OF HOT WATER PER DAY, 250 DAYS PER YEAR, HAS WATER ENTERING ITS HEATERS AT AN AVERAGE TEMPERATURE OF 70°F. THE WATER MUST BE HEATED TO 160°F TO COMPENSATE FOR A 40°F DROP DURING STORAGE AND DISTRIBUTION, IF IT IS STILL TO BE DELIVERED TO THE TAPS AT 120°F. HOT WATER IS GENERATED BY A NATURAL GAS-FIRED HEATER (SEASONAL EFFICIENCY = 0.45), USED YEAR ROUND WITH DOMESTIC HOT WATER AS ITS ONLY LOAD. THE FUEL HAS 1,030 BTU PER CUBIC FOOT.

1. What is the building domestic hot water load?
   - a. 209,978,235 Btu
   - b. 105,046,875 Btu
   - c. 176,439,098 Btu
   - d. 119,786,875 Btu
   - e. 98,605,409 Btu
2. What is the parasitic load?
   - a. 97,654,091 Btu
   - b. 37,870,005 Btu
   - c. 14,673,065 Btu
   - d. 53,873,947 Btu
   - e. 47,087,500 Btu

3. What is the total load?
   a. 154,837,936 Btu
   b. 132,847,530 Btu
   c. 152,134,375 Btu
   d. 197,354,837 Btu
   e. 176,938,736 Btu

4. What is the total energy used?
   a. 338,076,370 Btu
   b. 297,645,913 Btu
   c. 432,844,423 Btu
   d. 310,736,062 Btu
   e. 591,639,735 Btu

5. What is the total fuel consumption?
   a. 528,907 cubic feet
   b. 298,645 cubic feet
   c. 283,332 cubic feet
   d. 328,233 cubic feet
   e. 452,987 cubic feet

6. How much fuel would be needed for the same system if the delivery temperature were lowered to 90°F?
   a. 298,720 cubic feet
   b. 246,174 cubic feet
   c. 329,751 cubic feet
   d. 287,978 cubic feet
   e. 187,635 cubic feet

7. How much fuel would be conserved by lowering the delivery temperature to 90°F?
   a. 79,756 cubic feet
   b. 89,456 cubic feet
   c. 82,059 cubic feet
   d. 91,502 cubic feet
   e. 65,231 cubic feet

CASE B: AN OFFICE BUILDING HAS 700 OCCUPANTS, EACH OF WHOM USES 3 GALLONS OF HOT WATER PER DAY FOR 250 DAYS PER YEAR. THE WATER, AS IT ENTERS THE HEATER, IS AT 60°F, AND IT IS HEATED TO 140°F. THE SEPARATE OIL-FIRED HEATER HAS AN EFFICIENCY OF 0.75 AND FUEL COSTS $0.95 PER GALLON. THERE ARE 138,000 BTU/GALLON OF FUEL.

8. What is the total energy used per person per year at the 100% flow rate? (Use Figure 1.)
   a. 501×10^3 Btu
   b. 492×10^3 Btu
   c. 460×10^3 Btu
   d. 560×10^3 Btu
   e. 398×10^3 Btu

9. What is the total energy used per person per year if flow is reduced to 67% and temperature is reduced to 130°F? (Use Figure 1.)
   a. 265×10^3 Btu
   b. 213×10^3 Btu
   c. 356×10^3 Btu
   d. 310×10^3 Btu
   e. 298×10^3 Btu

10. How much fuel is saved per year by making the changes in Question 9?
    a. 872 gal/yr
    b. 712 gal/yr
    c. 672 gal/yr
    d. 742 gal/yr
    e. 534 gal/yr

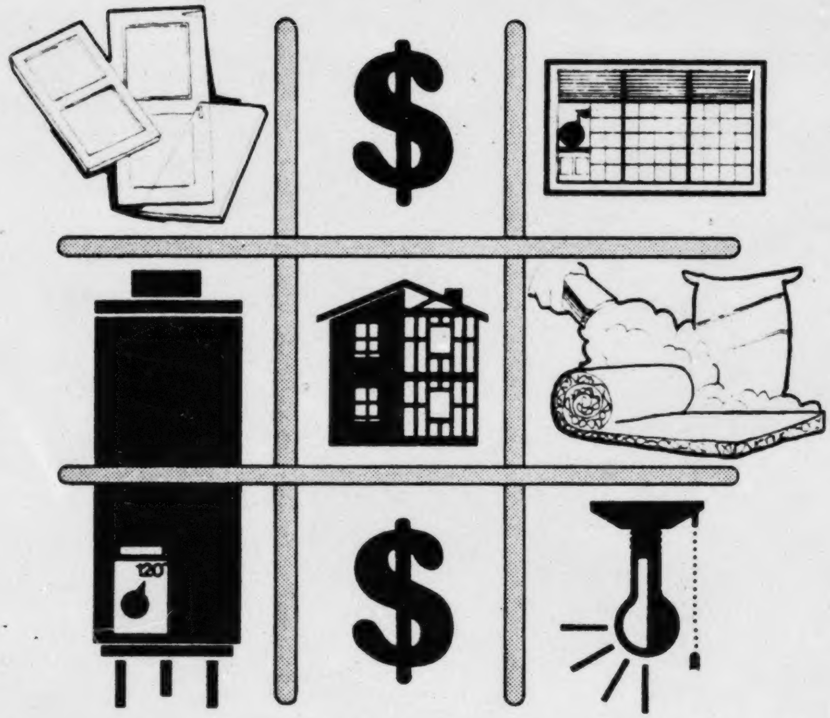
11. How much money is saved per year by making the changes in Question 9?

a. $832
b. $698
c. $973
d. $765
e. $705

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY AUDITS



MODULE EA-09

PROCESS ENERGY SYSTEMS

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

This module discusses the distinction between process energy and housekeeping energy. The processes of many large industries are so complex – and often unique to a particular installation – that groups of engineers are required to evaluate their energy consumption. The auditing of such processes is beyond the scope of this module; however, two process energy audits that the energy conservation-and-use technician may be called upon to perform are detailed. Emphasis is given to the necessity of thoroughly researching the process to be audited and retaining the assistance of qualified engineers when appropriate.

PREREQUISITES

The student should have completed Module EA-08, "Auxiliary Equipment Systems."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Discuss the different oven types and modes of heating.
2. Discuss heat balance as an auditing technique.
3. Calculate oven heat loss.
4. Discuss hearth furnace construction.
5. Discuss efficiency and economy of direct-fired heaters.

6. Discuss industrial furnace stack losses and furnace heat losses.
7. Discuss the relationship of draft and pressure to furnace efficiency.
8. Explain the operation of recuperators and regenerators.
9. Discuss the process of furnace reversal.
10. List and discuss energy conservation opportunities in open-hearth furnaces.

AUDITING PROCESS ENERGY

Process energy is defined as "that portion of a facility's energy-in that is consumed by production/manufacturing equipment and activities." Process energy can be contrasted to the energy required to run lighting, environmental control, and auxiliary equipment – or "housekeeping" energy.

When auditing a facility that houses energy-consuming processes, the energy use of housekeeping systems is audited in the same way as in residential, commercial, or institutional facilities. However, since processes account for 70% or more of the energy a facility consumes, they frequently offer the greatest opportunity for energy savings. Thus, the energy auditor must have a broad background in energy-consuming functions and access to resource material.

The process energy systems discussed in this module are a very limited sample of what the auditor of manufacturing/industrial processes may encounter. Many industrial processes are so complex and specialized that an entire staff of professional engineers is employed essentially to audit process energy consumption and recommend energy-conserving modifications. There are, however, an increasing number of energy use technicians who assist these engineers. These energy conservation-and-use technicians should develop research skills – in addition to the material in this module – to aid in finding information about a particular process, or part of a process, when necessary.

This module discusses the process energy characteristics of baking ovens and hearth furnaces. The intent is to demonstrate how to approach specific parts of the process energy audit encountered by the energy use technician. More complex and unique process energy systems require extensive research and/or the assistance of professional engineers.

BAKING OVENS

Basically, all ovens are part of a continuous production line, consisting of a tunnel chamber with a continuously moving band on which the product lies. The baking process is completed between the product's entering and leaving the chamber, by the application of heat from direct-fired gas burners, or indirectly by air heated in combustion chambers. All ovens have several control zones (usually seven or eight) that can be independently controlled to give any required temperature profile. Dampers are sometimes provided to control the flow of exhaust from each zone, which also controls (to some extent) the product temperature. Exhaust from each zone is discharged into the atmosphere.

The baking oven performs two basic functions:

- The baking process – chemically changes the state of organic compounds from an uncooked to a cooked state.
- The thermal dryer – removes a considerable percentage of moisture from the product, which is conveyed by air into the atmosphere. It also carmelizes the sugar content of certain biscuits, which is visible as the brown coloring of the product.

BASIC OVEN TYPES

The thermal operation of continuous tunnel ovens falls into two basic types: convective and radiant.

Convective Ovens

Convective ovens are usually larger than radiant ovens in cross-sectional area. Heat is applied to the product by internal oven circulating fans. The movement of air over a moist material at high velocities gives an increased moisture evaporation rate. Figure 1 shows the evaporating characteristics of ovens from several major oven manufacturers.

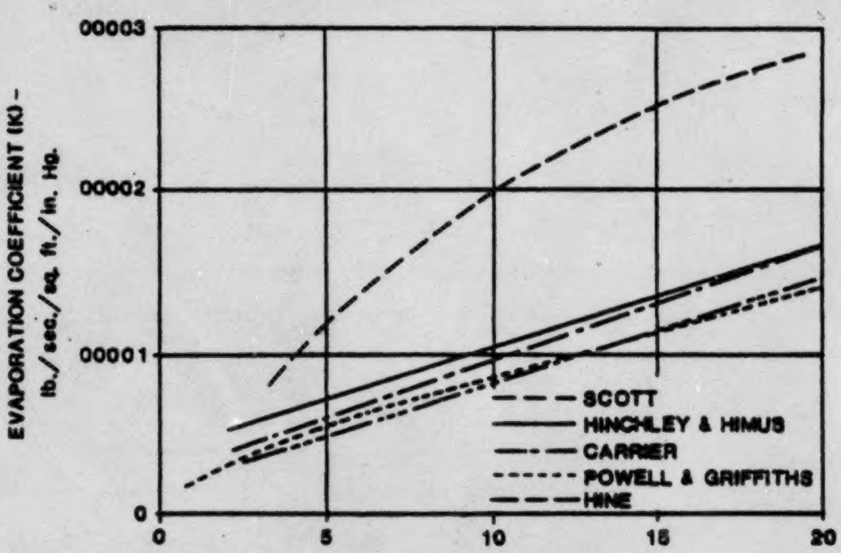


Figure 1. Influence of Air Velocity on Evaporation Coefficient (ft/sec).

Radiant Ovens

In radiant ovens, heat is applied to the product by direct radiation from the burner flames above the oven band. Heat is also conducted from the metal band, which is heated by the burners below it. Air movement in radiant ovens is at very low velocity.

Both convective and radiant ovens are provided with exhaust ducts to evacuate combustion products and moisture vapor. These exhaust ducts are usually fan-assisted and should have dampers to control the volume of exhaust.

MODES OF OVEN HEATING

The methods of heating an oven fall into four categories: direct-fired, indirect-fired, electric, and microwave.

Direct-Fired

The direct-fired oven is used in the Keebler Company's equipment and, as previously discussed, can be either radiant or convective. A clean-burning fuel (natural gas, propane, etc.) must be used with this heating method because combustion products are in direct contact with the food material.

Indirect-Fired

A heat exchanger, which generates hot, clean air, is positioned either above or at the side of an indirect-fired oven (Figure 2). The combustion products are kept completely separate from the hot air supply to the oven, preventing any possibility of contamination. This enables the use of a wider range of fuels (#2 to #6 oil) and also permits the use of multi-fuel installations.

Indirect-fired ovens are normally of the convective type. However, radiant types have been designed that use "heat transfer oil" systems.

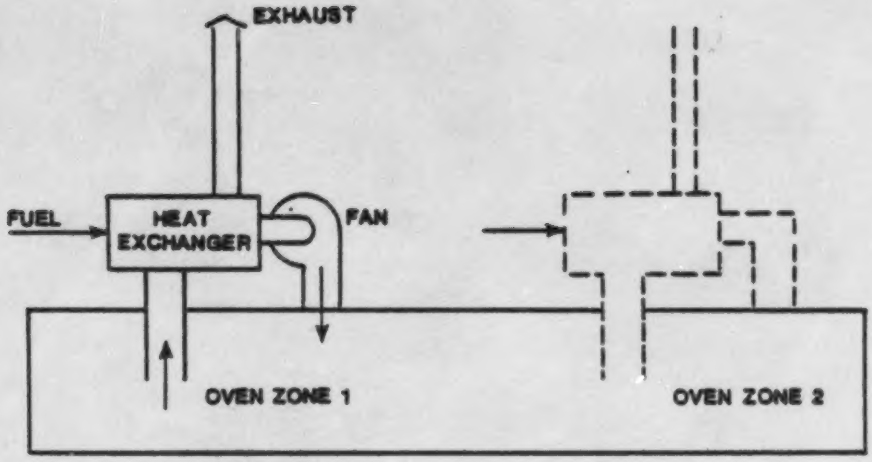


Figure 2. Indirect-Fired Baking Oven.

Electric

This form of heating can be applied to either a convective or radiant oven. Electric resistance heating elements are used for the heat source, and stepped temperature control is usually obtained by stage switching of banks of heating elements. Variable temperature control can be obtained by using such devices as thyristors.

Microwave

This is a newly developed form of heating for industrial food processing application. The principle consists of passing a very high-frequency electric current through the material to be heated. The microwave oven has a very limited scope for energy conservation.

OPERATIONAL CONTROL

The controls available to the oven operator are: band speed (bake time), zone temperatures (above and below the band), and zone and oven exhaust dampers. Exhaust dampers control oven humidity and turbulence.

There is no set operational procedure for a particular product. Most oven controls are set to the requirements of each baking oven superintendent. Each oven may be set differently by the operator at the change of every shift.

Despite the variations in operational control, output, and product quality, the required standard is achieved. The explanation given for the present methods of oven control is that baking is an "art" and that there are too many indeterminate factors that cannot be automatically controlled.

In order to evaluate the scope for energy conservation, a full thermal analysis must be undertaken for each product line and oven type. Each aspect of thermal operation should be examined in detail and a comparison made of actual system efficiency.

HEAT BALANCE

The thoroughness of data collected for preparation of a heat balance is a function of the staff's ability to conduct the tests and the availability of instrumentation.

The overall objective is to evaluate the scope of energy conservation and determine, in practical terms, how it can be applied. It may be helpful to show energy flow in the system diagrammatically. This should be based on overall machine operation, even though the baking oven is a multizoned control system. Figure 3 shows a natural gas-fired, 7-zone oven with a double pipe gas-burning system. The diagram in Figure 4 shows oven energy use.

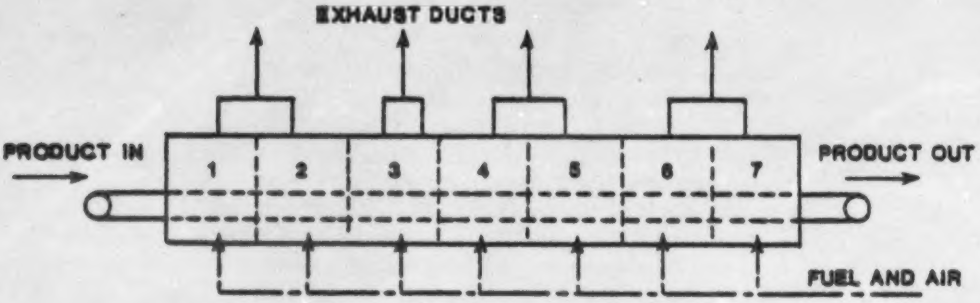

EXHAUST DUCTS
PRODUCT IN
1
2
3
4
5
6
7
PRODUCT OUT
FUEL AND AIR

Figure 3. 7-Zone Baking Oven.

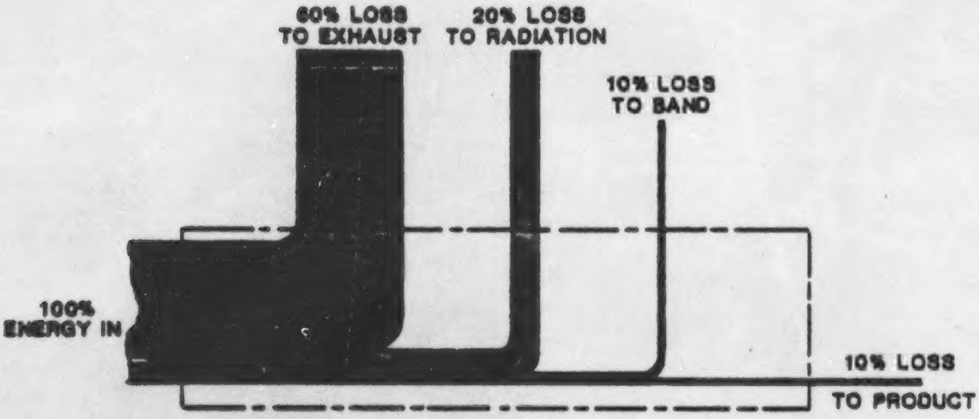

60% LOSS TO EXHAUST
20% LOSS TO RADIATION
10% LOSS TO BAND
100% ENERGY IN
10% LOSS TO PRODUCT

Figure 4. Energy Diagram (Sankey).

Heat balance is evaluated in terms of heat supplied and heat losses. The procedure used to evaluate energy consumption throughout various stages of the baking process is described in the following paragraphs. The accuracy of the evaluation depends on the facilities and instrumentation available.

- Fuel Measurement: This is essential if a meaningful thermal analysis is to be obtained. Ideally, a gas flowmeter should be installed in the main supply pipe. An alternative would be to evaluate the gas flow to each burner by measuring gas pressure at each zone and referring to the injector orifice rating. However, this method is less accurate.

- Uncooked Product: The temperature of an uncooked product in the oven can be measured by a thermometer or thermocouple, in °F. The moisture content should also be determined (by weight) and the percentage moisture (H_2O) and solids noted. The final data required is the rate of production in pounds per hour.

- Evaporation of Moisture Vapor: This requires that a sample product be removed from each zone. As the sample leaves the oven, its temperature should be noted and an evaluation made of the percentage moisture and solids. Total moisture vapor (lb/hr) can be determined by calculation of this data.

- Combustion Products: Exhaust stack temperatures should be measured in °F. A sample hole placed in the stacks at a proper location will ensure a satisfactory reading. At the same point, an analysis should be taken of the stack gases to measure carbon dioxide (CO_2), carbon monoxide (CO), and oxygen (O_2), using an Orsat or equivalent equipment. Provided the sampling position is satisfactory and turbulence in the duct is not excessive, a velocity measurement should also be taken. Analysis of this data enables calculation of heat loss through the exhaust system.

- Oven Casing Radiation: Surface temperature measurements of the oven casing can be measured easily with a surface pyrometer. Tables for the evaluation of heat losses from flat surfaces are available in ASHRAE Handbook of Fundamentals and are sufficiently accurate to indicate overall heat loss.

- Band Losses: This is virtually impossible to measure, as it may enter at the burner or at other places in the oven casing, such as the oven entrance and exit, open doors, etc. Its determination can, therefore, only be by calucation from the analysis of the oven exhausts.

Final heat balance should be presented as follows:

Heat supplied:		
Fuel burned in oven	Btu/hr	100%
Heat losses		
Dry heat content of exhaust	Btu/hr	%
Moisture heat content of exhaust	Btu/hr	%
Sensible heat gain to product	Btu/hr	%
Radiation from oven	Btu/hr	%
Radiation from band	Btu/hr	%

ENERGY CONSERVATION – EVALUATION OF SCOPE

There are only two aspects of the baking process that are beyond the scope of energy conservation: temperature and time of bake. Every other aspect can be examined for possible modification or adjustment to achieve economy in fuel use. The following discussion examines each aspect of the baking process and demonstrates how the thermal efficiency of the system can be improved.

MOISTURE INTO THE OVEN

Each product recipe specifies the percentage moisture of the mix (before baking) and the final moisture of the product upon leaving the oven. For example, a sweet biscuit recipe may have a 25.9% moisture per 74.1% solids content going into the oven and a 7% moisture per 93% solids content going out of the oven. A reduction in the recipe of only 1% in the moisture evaporated in the oven would show a savings of approximately 1.87% in fuel consumption.

It is not always possible to reduce the moisture content of the recipe or the amount to be evaporated during the bake. However, these figures demonstrate the importance of accurately controlling the moisture contents of the process. Figure 5 shows the effects of controlled moisture content and temperature.

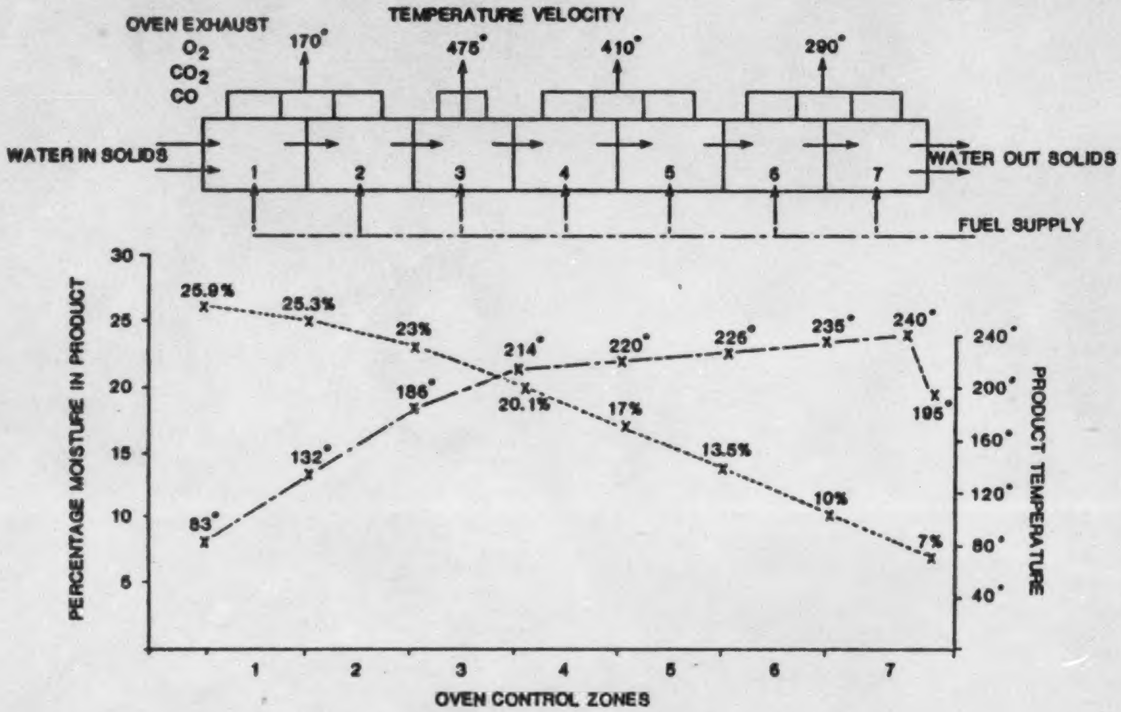


Figure 5. Product Moisture Content and Temperature.

COMBUSTION EFFICIENCY

For both atmospheric and sealed double-pipe burners, it is essential that the correct air-to-fuel ratio be maintained throughout the full range of burners.

Correct burner aeration can be set by visual inspection of the flames on the burner bar. The atmospheric burner has a series of holes, and the flame shape is conical, blue, and about two inches long. Aeration is controlled by adjustment at the venturi. Heat output can be controled by adjusting the gas pressure.

For maximum operating efficiency, the burners can be set up to operate at not more than 20% excess air supply. This would give a normal product a combustion analysis of 9.6% CO_2 and 3.8% O_2 by volume.

Excessive burner aeration gives rise to higher mass airflows through the oven and results in waste fuel. For example, a burner operating at 50% excess air uses 3-8% more fuel than at 20% excess air. At 100% excess air, fuel loss rises to 9-25% (over 20% excess air levels).

The air supply required for combustion is drawn from the room in which the ovens are located. If an adequate make-up supply is not provided, air starvation occurs. This is a negative pressure situation in the room, which is particularly disturbing for amospheric-type burners.

EXHAUST HEAT LOSS

The only gases flowing up the oven exhaust stacks into the atmosphere should be the combustion products of the fuel and the air required to convey the moisture removed from the product. As the exhaust from the oven is fan-assisted, it is possible that a greater than necessary flow of exhaust is being induced, which is very wasteful of energy.

Control of combustion efficiency, mass of heat flow and vapor through the oven, and volume of exhaust ejected into the atmosphere are all closely related. The scope for energy conservation in these areas of oven operation could be up to 10% of current fuel consumption levels.

RADIATION FROM OVEN CASING

Radiation from oven casings is not a very large percentage of the total heat supplied to the oven. However, an adequate level of thermal insulation is essential, and regular inspection of the casing and periodic checking of its temperature with a surface temperature pyrometer is recommended.

The exposed surface area of an oven 270 ft long x 4 ft high x 5 ft wide would be about 3500 sq ft. Average heat emission from a flat metal surface (horizontal and vertical radiation plus convection) is about 2 Btu/hr/ft^3/°F above ambient. If the room temperature were 120°F, the overall heat loss would be 210,000 Btu/hr. For example, an oven using 2,850,000 Btu/hr represents a loss of 7.4%. A rise in surface temperature of only 10% increases heat loss by an additional 70,000 Btu/hr, representing an increase in overall fuel loss of 2.5%. A partial degradation of the thermal insulation could easily cause this to occur, and it would not noticeably affect oven operation.

BAND HEAT LOSSES

This area of heat loss can be grossly underestimated. There are two basic types of bands: mesh and solid.

An average band is approximately 38 inches wide, with a maximum width of 42 inches. The speed at which the band travels through the oven can vary from 30 to 150 feet per minute. The maximum band temperature is the same as that of the product (to about 280°F). For example, a band moving at 700 feet per minute in a 282-ft long oven would have a residence time of 2.82 minutes. Simple measurements can be taken to yield the heat losses. Equation 1 is used to calculate these losses; calculations are shown in Example A.

$$\text{Heat loss } Q = \text{weight} \times \text{specific heat} \times \text{temperature differential}$$

Equation 1

EXAMPLE A: HEAT LOSS CALCULATION.

Given: Band speed – 50 ft/min
Band width – 38 inches
Band thickness – 0.055 inches
Specific heat – 0.21 Btu/lb/°F
Maximum band temperature – 240°F
Minimum band temperature – 220°F

Find: Heat loss.

Solution: Weight = 50 ft/min x 60 min/hr x 38 in/12 in x 0.055 in/12 in x 485 lb/ft^3
= 21,118 lb/hr
Heat loss Q = 21,118 x 0.21 x 20
= 88,696 Btu/hr

The loss shown in Example A would be equivalent to a loss of 3% of the total heat supplied, based on an overall oven heat consumption of 2,850,000 Btu/hr.

If doors or other parts of the oven are opened during the baking cycle (for extra cooling of the product or any other purpose), it would be possible to increase the cooling of the band from 220°F to 200°F or lower. The heat loss would increase proportionately and, thus, reduce the overall thermal efficiency of the oven. For the purpose of energy conservation, it is important to reduce the rate of heat losses from the band to a minimum.

A similar evaluation can be performed for a mesh band that has a density of 4.2 lb/ft^3. For this type of band, the temperature drop can be up to 50°F. This represents a much higher percentage of total heat loss, which could be in excess of 10%. Therefore, minimizing band heat losses is very important.

ATMOSPHERIC BURNER SYSTEMS

One of the principal disadvantages in setting up the atmospheric burner system for correct air-to-fuel ratio is the problem of negative pressure in the building in which the ovens are located. This is caused by the requirement for combustion air being taken from the building. At the present time, most oven burner systems are of the premix type, and few problems are encountered.

COMBUSTION AIR REQUIREMENTS

A typical oven utilizes approximately 11 cubic feet of air per cubic foot of gas burned. For a typical oven, the fuel requirements are between 3,000,000 and 6,000,000 Btu/hr. The following shows combustion air requirements based on average cubic feet of air requirements:

Fuel used – 4,500,000 Btu/hour

Calorific value of fuel – 1025 Btu/cubic foot (natural gas)

4390 cubic feet/hour

Air required – 48,290 cubic feet/hour at 11 cubic feet/cubic foot gas

The heat required for increasing the temperature of the combustion air could be extracted from the oven exhaust. The capital cost of such a project would require development and would probably result in a single combustion air system for several ovens. All heat necessary for heating combustion air is available from the exhaust, and the horsepower required for fans would be small.

Filtration of the combustion air would ensure hygienic conditions. (At present, air infiltration is not filtered.) Airflow balancing of the whole plant would improve the conditioning of other areas.

HEARTH FURNACES – ELEMENTS OF FURNACE CONSTRUCTION

The elements from which furnaces are built are simple and well known; however, they are briefly described at this point.

In most furnaces, the stock or charge to be heated rests on a hearth. In order to protect the foundation and prevent the hearth from becoming soft and mushy, open spaces are frequently provided under the hearth for the circulation of air; the hearth is then said to be ventilated. Fuel and air enter the furnace through ports or burners. The burners fire through burner tiles. The combustion products leave the furnace through vents and pass through flues to the stack.

The furnace interior can be observed through peepholes or sightholes. The heating chamber is surrounded by the sidewalls carrying the roof, which is usually in the shape of an arch resting with its skewback on the sidewalls or on external steelwork. The support for the skewback is known as the abutment. Skewbacks form the spring of the arch, and the highest point of the arch is called the crown. The distance between the crown and the chord joining the skewbacks is called the rise of the arch.

The thrust exerted by the arch is taken up by the binding, which consists of vertical buckstays (made of iron or steel castings, rails, or structural material) and the tie rods, or tie channels, that hold the buckstays together. As a rule, the roof is arched in one direction only. If the arch is curved in two directions, it is known as turtleback arch. Arches are laid up in rings or are bonded. When laid up in rings, the arch consists of a number of separate layers; when bonded, the bricks on one row reach over into the next row. Figure 6 illustrates the difference. The roofs of modern, large furnaces are suspended and are not necessarily arch-shaped.

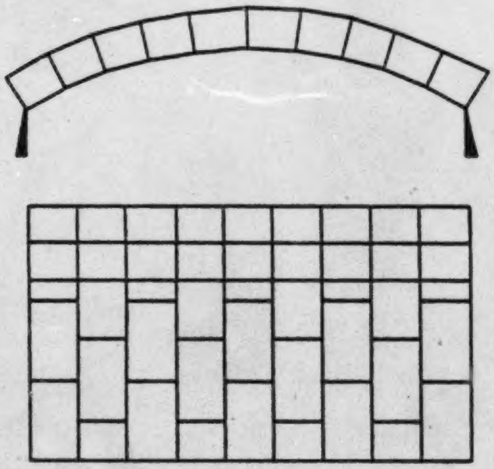


Figure 6. Methods of Laying Brick Arches.

The most common material for furnace construction is firebrick, which is made of fireclay. Firebricks are classified as super-duty, high-duty, intermediate-duty, and low-duty brick. Low-duty bricks contain minerals that lower the softening point of the bricks. The bulk of the brickwork is built up of standard bricks, the size of which for many years has been 2-1/2" and 3" series. In each series, a brick of half the standard thickness is known as a "split," while a brick of half the width is called a "soap." In order to avoid expensive cutting of bricks, furnaces are built in multiples of brick dimensions. All makers of firebrick regularly make arch brick, wedge brick, doorjamb brick, and bricks of many other shapes listed in catalogues and price lists. Price lists can be obtained from any supplier. Special shapes are made to order and are more expensive than standard shapes listed in catalogues. For the purpose of reducing heat loss, furnaces are frequently built of insulating firebrick (also called lightweight firebrick) or covered with a finely-divided, refractory insulating material. Lightweight bricks also serve as insulation by backing up dense firebricks. Firebricks are seldom laid dry; as a rule, they are laid with a thin layer of mortar between them. Occasionally, firebricks are protected against the heat and furnace atmosphere by a wash, which is either brushed on or sprayed (shot) by a furnace gun.

Other materials for walls and roofs of furnaces are plastic fireclay and hydraulic heat-resistant concrete (castable).

DIRECT-FIRED HEATERS

Direct-fired heaters have the flame and products of combustion directly in contact with the material to be heated. Many industrial furnaces use this design to heat a component to a desired temperature before performing additional manufacturing operations. Other direct-fired furnaces indirectly heat the product to a desired temperature to allow a chemical reaction to take place. The design of heat recovery systems for direct-fired furnaces is complex and specialized; hence, a general understanding of how such furnaces operate is appropriate for recognizing the potential for energy conservation.

ECONOMY AND EFFICIENCY

When used in connection with direct-fired heaters, "economy" and "efficiency" refer to the heating cost per unit weight of finished product. Therefore, heating cost includes not only the cost of fuel but also the cost of firing and tending the furnace, amortization, the cost of maintenance and repair, and the cost of burned, spoiled, or otherwise rejected pieces. Furthermore, it includes the cost of machining those pieces which, at inspection, are found to be defective because of improper heating. Finally, it includes the cost of handling the material as it goes into and out of the furnace.

With so many different factors entering into the heating, it is possible that, in some cases, the highest priced fuel or other source of heat energy will ultimately be the cheapest in relation to total heating cost. In heating of certain metals (for example, steel), part of the heat is furnished by oxidation of the charge. The heat of combustion of iron or steel is 2420 to 3240 Btu per pound of metal (depending on the kind of oxide formed) with an average 2850 Btu per pound. If steel is heated to 2200°F, from 1% to 4% of the weight of the charge is usually lost by scaling. Consequently, 57,000 to 230,000 Btu per net ton of steel originates in the oxidation of part of the charge. This is a minor fraction of the heat consumption of a direct-fired heater; however, this fraction is very expensive since steel (2850 Btu/lb) costs more than fuel oil (140,000 Btu/gal) or natural gas (1000 Btu/ft^3). Many such units burn fuel with a deficiency of air (reducing atmosphere) to control the oxidation of the product.

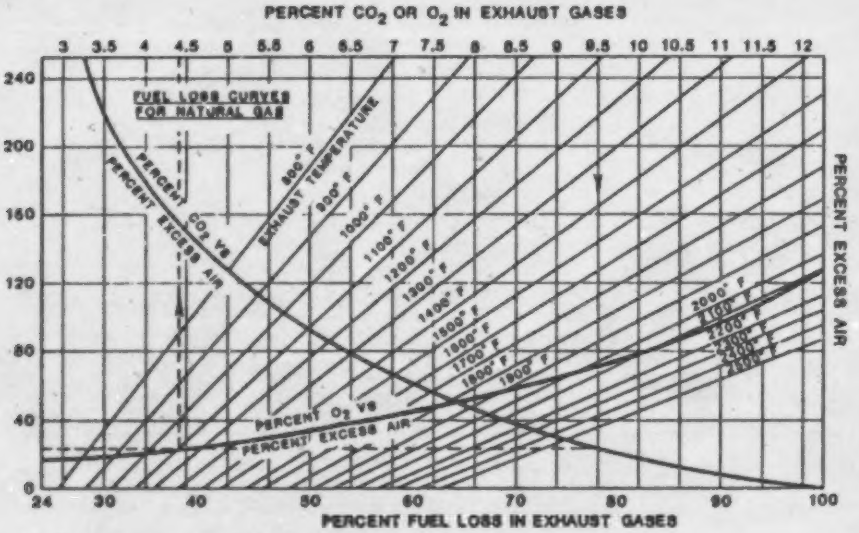
There are many types of direct-fired heaters in which fuel cost is the outstanding item of expense and in which fuel economy is worthy of study, in addition to other factors comprising total heating cost. Moreover, it is necessary to know the fuel consumption of a furnace in order to select the optimum size and number of burners, dimensions of ports, vents, and stacks; and correct size for auxiliary equipment.

Direct-fired industrial heaters often have very low thermal efficiencies. Whereas steam-generating unit efficiencies range from 60% to 90%, direct-fired heater efficiencies are sometimes as low as 5% in combustion types and not significantly higher in electric types (if thermal efficiency of electric energy generation is included in computing efficiency). With favorable conditions, excellent design, and good operation, direct-fired heaters can offer efficiencies up to 60% or slightly higher; however, such high values are the exception rather than the rule. "Efficiency" refers to "fuel efficiency" – the ratio of the heat input into the product to the heat available from the fuel.

One reason for the differences in thermal efficiency between steam-generating units and direct-fired heaters is the high final temperature of the material heated. Gases can give up heat to the charge only if they are at a higher temperature than the charge. Consequently, the flue gases leave direct-fired heaters at a very high temperature, except for a short time after a cold start.

INDUSTRIAL FURNACE EFFICIENCIES

The products of combustion should leave an industrial furnace at a temperature 50°F in excess of that of the charge; hence, two almost straight curves are shown in Figure 7. These curves indicate the highest possible thermal efficiency of industrial furnaces as a function of furnace temperature. The curves for maximum possible efficiency were calculated for simple furnaces without preheating of the charge, fuel, or air. As a rule, the thermal efficiency of industrial furnaces lies far below the value indicated by the right-



Example: CO_2 in Exhaust Gas = 9.9%. Exhaust Gas Temperature = 1000°F. Percent Excess Air = 24%. Fuel Loss Out of Stack = 54.4%. O_2 in Exhaust Gas = 4.4%.

Figure 7. Industrial Furnace Stack Losses.

hand curves. The discrepancy is particularly noticeable in low-temperature furnaces. The reason for this discrepancy lies in the fact that the combustion products in low-temperature industrial furnaces dissipate high heat before they come in contact with the charge. The amount of useless dissipation of heat varies with the design of the furnace. Consequently, the thermal efficiency of industrial furnaces varies within a wide range. The two lower curves include a bank of probable efficiencies of average industrial furnaces in which there is no salvaging of heat.

HEAT LOSSES

The low overall thermal efficiencies experienced in industrial furnaces are explained by a clear understanding of the heat distribution in a simple industrial furnace. This heat distribution is illustrated in Figure 8. The heat is liberated in the combustion chamber and a portion of the heat passes into the charge. Some of the remaining heat passes into the furnace walls and some into the hearth, increasing their temperatures. Heat is lost to the surroundings by radiation and convection from the outer surface of the walls, by conduction into the foundations, through cracks

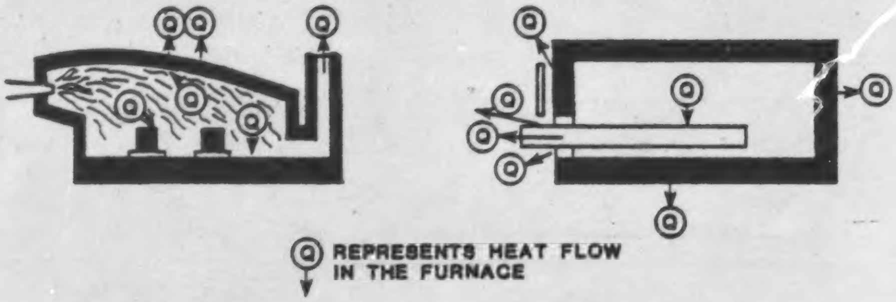


Figure 8. Heat Flow in a Furnace.

or other openings and around the door, by conduction and radiation for a partially exposed charge, and by the ignition of fuel in the flues.

Certain heat losses are peculiar to certain furnaces. In furnaces that heat only part of a long piece of metal, heat passes out along the metal from the part inside the furnace to the part outside the furnace and is dissipated into the surroundings. In electric furnaces, heat is lost in the conduction of heat through the terminals or electrodes.

Water-cooling of skid pipes and conveyor rollers absorbs large quantities of heat and lowers themal efficiency. If the charge is heated in containers or on traveling chains, a large part of the heat is dissipated into the open after the devices leave the furance. Finally, heat passes out with the products of combustion in the form of sensible heat or as undeveloped heat of combustibles that have escaped unburned.

Fuel economy demands that the fraction of total heat that passes into the stock be as large as possible. The first step toward achieving this goal requires the solution of two problems: first, determination of heat losses and methods of reducing them; second, determination of the quantity of fuel or electric energy required for heating a given amount of metal to a given temperature in a given furnace.

The greatest contributor to heat loss in industrial furnaces is furnace stack loss. This loss includes the sensible heat in combustion products, the latent heat of water vapor, plus the heating value of any unburned fuel or carbon monoxide. Even in a closely-controlled furnace, this loss can be 40% to 60% of the heat content of the fuel burned. Other areas of heat loss should not be ignored. It is very important, for example, that all unnecessary furnace openings be sealed to prevent furnace gases from escaping to the surrounding area. However, these losses are usually minor compared to stack loss. The magnitude of stack loss from an industrial furnace is a function of the furnace temperature, which is determined by the product processed. Also, stack loss is dependent on furnace pressure and completeness of combustion.

In most industrial furnaces, the escape of a considerable amount of unburned combustibles in the flue gases is unavoidable. This is due to the necessity for maintaining a nonoxidizing atmosphere in the heating chamber to avoid excessive scaling or oxidation loss of the stack. Furthermore, even in those furnaces in which an oxidizing atmosphere is permissible, stratification of the gases often persists to such an extent that the amount of heat lost depends not only on the design of the burners and furnace, but on operating requirements as well.

FURNACE DRAFT AND PRESSURE

When considering the pressure conditions in heating and annealing furnaces, the following rules must be observed:

1. In the heating of metals, the pressure in the heating chamber must be atmospheric, or only very slightly in excess of atmospheric, at all heating rates.
2. The lower the temperature to which the material is to be heated, the greater the necessity for thorough circulation of gases in the heating chamber, especially if piped or coiled material is to be heated rapidly and uniformly.

If the pressure in the heating chamber were much greater than atmospheric, flame or hot gases would be discharged from all openings. If it were much lower, air would be drawn in and the material would be oxidized and scaled. (Excess air in the heating chamber does not affect ceramic materials.)

In a tall furnace, it is impossible to have atmospheric pressure at all levels because the furnace forms a chimney or stack. Since there must be a difference between atmospheric and furnace pressure at some level of the furnace, the question is how to distribute that difference. To prevent the entry of air, furnace pressure from the hearth up is almost invariably above atmospheric pressure, with the excess at the hearth being as little as 1/200 inch of water pressure while the excess pressure at the crown of the arch is much greater, depending on the height and temperature of the furnace. Furnace operators test the furnace pressure that prevails near the hearth by watching for a "stringer" of flame or hot gas issuing from an observation hole in a furnace door. Fine dust dropped in front of the door opening intensifies the indication.

It is easier to maintain the desirable condition of carrying a small pressure at the level of the hearth if the discharge ports for combustion products are located in or near the hearth rather than near the roof. With an opening in the roof, the furnace becomes a chimney that draws in cold air around the door (or through it, when it is open) and through all the cracks and crevices, unless the outlet is so restricted that its resistance counterbalances the chimney effect.

Restriction of a top outlet can be accomplished by using a damper. However, dampers must be manipulated frequently in order to adapt the resistance of the outlet to the flow rate of the flue gases. Since the hot gases rise directly to the hole in the roof with the shortest possible travel, the heated stock lies in a dead mass of comparatively cold gas and receives heat by radiation only.

In the range of temperatures for which furnaces of this type are used, radiation is comparatively weak. Therefore, circulation of gases around the charge is needed (Figure 9). It should be noted that a short path of gases in a furnace keeps them from giving up much heat and permits them to escape with a temperature considerably above that of the furnace interior.

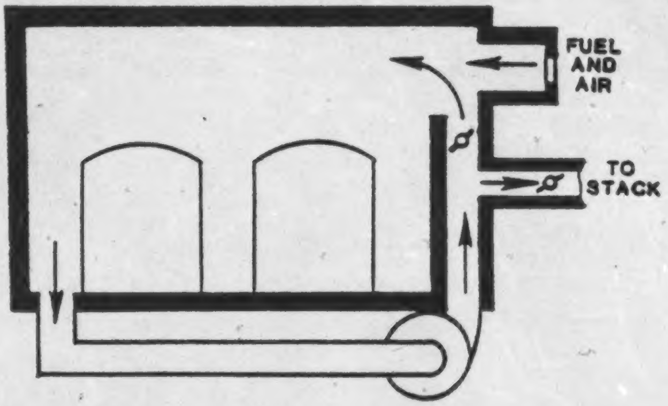


Figure 9. Recirculating Furnace.

If the outlet port is located at the bottom, then the old saying that "the flame must lick the hearth" can be put into practice, although it may have to be modified by substitution of "heat" for "flame" if the current of gases is clear and invisible. With this arrangement, buoyancy tends to keep the hot gases in the furnace instead of sweeping them out.

In order to maintain the proper pressure in the furnace, correct port location alone is not sufficient – port size must also be considered. Again, it must be kept in mind that a slight excess pressure is to be maintained in the furnace. Therefore, the purpose of ports, flues, and stacks is not limited to creating draft in the furnace, but to using the heat efficiently before carrying away the products of combustion. In this respect, many heating furnaces are different from boiler furnaces, in which the stacks draw air through the fuel beds. The combination of flue and stack must be of such dimensions that the draft, which it produces in conjunction with the furnace pressure, equals the sum of the velocity head and the friction head.

In order for this condition to exist at all rates of heating, there must be a delicate balance between flue gas flow, flue and stack opening, and stack temperature. This balance is not easily maintained in practice solely by the size of vents and flues. Flues are usually made too large, and dampers are provided for balance control. This arrangement places the furnace at the mercy of the attendant who, by working at all times with a wide-open damper, may draw vast quantities of excess air into the furnace, to the detriment of both fuel economy and product quality. In large and critical furnaces, the dampers are moved automatically (by power) and "balanced draft" is maintained in the heating chamber by draft-controlling devices quite similar to those used in connection with boiler furnaces working with forced draft.

An adjustable opening near the lower end of the stack is a convenient and effective method of controlling the draft. It is not always reliable, however, because the entering cold air gradually changes the temperature of the wall of the stack. Changes in wind velocity and direction also exert an erratic influence. The adjustment is not stable. In a large number of furnaces, an effective pressure-regulating device is to resort to flues and stacks made too large, and flue ports placed quite close to the door or doors, with care taken that the doors fit loosely at the bottom corners.

Under average operating conditions, cold air is drawn in through the door whether it is closed or open. The air cannot do much damage because it short circuits itself directly into the flue without reaching the interior of the heating chamber. The cold air reduces the demand of the stack by depressing the stack temperature and satisfies the remaining demand by increasing the volume flow without perceptibly cooling the furnace.

In long, narrow furnaces of the batch type, ports are needed along the entire length; all ports cannot be located near the door. In this case, a hole near the bottom of each vertical flue will accommodate a wide range of firing. The same purpose is served by thin-walled vertical flues that give off heat to the surroundings. When the furnace is driven hard, the flue temperature is higher and the draft is better. Of course, none of these semi-automatic methods works well when the furnace is fired up from a cold condition.

Even if the expedient of making the ports "slightly too large" is employed, the approximate size of the ports must still be determined. The solution to this problem involves two steps: One consists of computing the quantity of combustion products in unit time; the other, in fixing the velocity with which the products flow through the ports and flues so that they create neither draft nor excessive back pressure. A technically correct solution to the problem would involve (1) the proper heating capacity of the furnace and (2) the fuel consumption. For large, special furnaces, the procedure is indeed necessary; but for the ordinary run of commercial furnaces, it is out of the question since the quantity and shape of material to be heated are seldom known beforehand. For this reason, it pays to derive average figures and to base flue sizes on them. The flues will be too large in many cases, but a tile properly placed across the top of each flue will produce the proper back pressure.

STACK GAS LOSSES

The existence of stack gas loss was realized quite early in the development of furnaces. Steps were taken to minimize stack gas loss by utilizing the sensible heat of the flue gases. This can be accomplished by using one or more of the following methods:

- Preheating the cold charge, using flue gases
- Preheating the combustion air (and/or fuel)
- Generating steam, using waste-heat boilers

Preheating Cold Charge

This method was first practiced in the use of preheating chambers and appears in its most effective form in some continuous furnaces. If a preheating chamber is provided, a considerable fuel savings can be obtained. The amount saved depends principally on the temperature of the main heating chamber and on the size of the preheating chamber in relation to the size of the finishing chamber. If the chamber sizes are properly related to each other and to the size of the heating stock, and if the furnace design and operation are correct, the products of combustion will leave each chamber with a temperature approximately 100°F above that of the chamber.

Preheating Combustion Air or Fuel

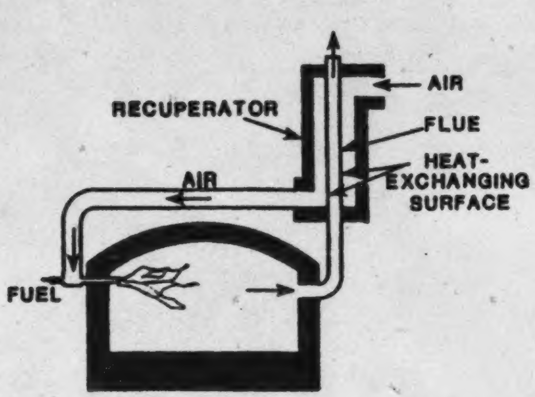
This method of improving the economy of combustion-type furnaces consists of utilizing the heat of the stack gases for the preheating of combustion air, fuel, or both. In connection with this method, three questions are of practical interest:

1. What fraction of the fuel can be saved by preheating either the fuel or the air?
2. What type and what area of heating surface are required for preheating?
3. Under what conditions is it advisable to use preheating devices?

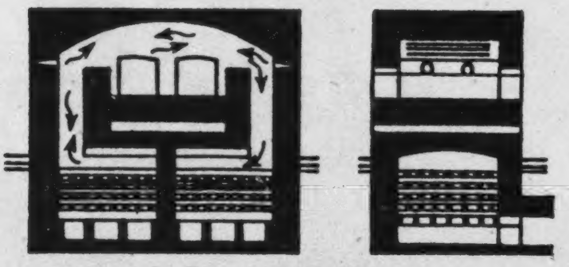
The fraction of fuel saved by preheating the combustion air can be computed by using the mean molal heat capacity of air at constant pressure for the temperature range of 65°F to the desired preheating temperature. Total mass of the combustion air is preheated to 400°F and used in firing fuel oil. The reduction in fuel consumption ranges from 9% with an exit gas temperature of 1600°F to 14.5% with an exist gas temperature of 2600°F. Similar reductions are available with other fuels. Increasing preheating temperature increases percentage fuel reduction.

Preheating combustion air also results in quicker combustion. With slow-burning fuels, such as blast-furnace gas and producer gas, quicker combustion is considered to be an advantage; however, with quick-burning fuels, such as city gas or coke-oven gas, it is often considered to be a disadvantage. With quick combustion, it is difficult to produce a long flame that extends all the way across the hearth. For that reason, experienced furnace engineers occassionally limit the preheating temperature of air.

There are two distinctly different methods for preheating combustion air. In one method, the outgoing flue gases transfer a part of their heat to the incoming air in a steady flow through a wall. This heat exchanger is called a recuperator, and the furnace is said to be recuperative. In another method, the outgoing combustion products impart heat to brickwork or to metal plates in a heat-exchanger chamber, which had previously been heated by the flue gases. The direction of the hot gas flow is reversed at regular intervals. This furnace is said to be regenerative. Recuperative and regenerative furnaces are illustrated in Figure 10.



a. Recuperative Furnace

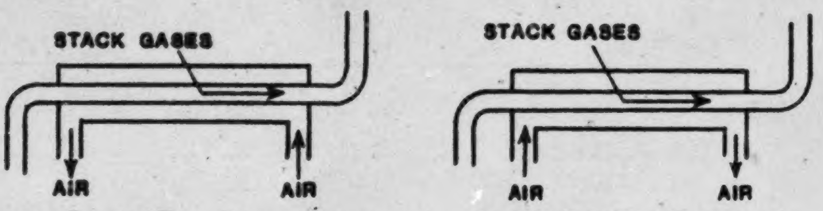


b. Regenerative Furnace

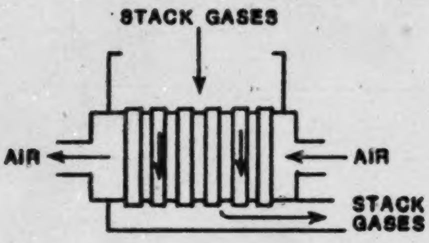
Figure 10. Recuperative and Regenerative Furnaces.

Recuperators can be subdivided into three classes according to the flow of the stack gases and the air: counter-flow, parallel-flow, and cross-flow (Figure 11).

Parallel-flow maintains the lowest maximum temperature at the recuperator walls. Because of this lowest maximum temperature, parallel-flow is used in connection with metallic recuperator walls whose temperature must be kept comparatively low.



a. Counter-Flow Recuperator b. Parallel-Flow Recuperator



c. Cross-Flow Recuperator

Figure 11. Types of Recuperators.

Some designs combine the three types of recuperators. Cold air is caused to circulate around the hot end of the tubes or plates in order to keep them cool. It is then bypassed to the cold end, and from there flows with a combination of cross-flow and counter-flow toward the hot end again. On the air side, the heat-transfer coefficient increases as air velocity increases. Therefore, it is desirable to pass the air through at high velocities in order to reduce the size of the recuperator. This is practicable up to the speed at which the increased cost of power for moving the air against the corresponding pressure balances the reduction of the cost of the recuperator.

On the flue-gas side, however, this rule does not hold. An increase in velocity, although it increases the convective heat transfer, requires that the gas passages be reduced in width for a given quantity of gases, thereby decreasing gaseous radiation. The net result may actually be a decrease of the total heat-transfer coefficient on the gas side. Equations for heat transmission in recuperators are given in Table 1.

TABLE 1. GENERAL EQUATIONS FOR HEAT TRANSMISSION IN RECUPERATORS.

$$W_{gas}\,(T_{gas\ in} - T_{gas\ out})\,Cp_{gas} = U\,A\,\Delta T_{mean}$$

$$W_{air}\,(T_{air\ in} - T_{air\ out})\,Cp_{gas} = U\,A\,\Delta T_{mean}$$

$$Q_{stack\ gas} = Q_{air}$$

$$Q_{stack\ gas} = W_{gas}\,(T_{gas\ in} - T_{air\ out})\,Cp_{gas}$$

$$Q_{air} = W_{air}\,(T_{air\ in} - T_{air\ out})\,Cp_{air}$$

$$W_{gas}\,(T_{gas\ in} - T_{gas\ out})\,Cp_{gas} = W_{air}\,(T_{air\ in} - T_{air\ out})\,Cp_{air}$$

where:

W_{gas} = lb gas/hr

W_{air} = lb air/hr

T = Temperature of air, °F

Cp = Specific heat of gas or air, $\frac{\text{Btu}}{\text{lb} - {}^\circ\text{F}}$

U = Overall heat transfer coefficient, $\frac{\text{Btu}}{\text{hr} - \text{sq ft} - {}^\circ\text{F}}$

A = Heating surface sq ft

ΔT_{mean} = Log mean temperature difference – air and gas, °F

From a heat-transfer standpoint, the best design of a recuperator causes the flue gases to travel slowly in large passages, while the air is passed through at high velocity. In metallic recuperators, the latter requirement is easily fulfilled; in tile recuperators, the joints cannot be made and kept tight, in spite of the greatest care. Even a slight excess of air pressure over that of the gases keeps both air and gas velocities low and makes up for the reduced convection heat transfer by providing a secondary or indirect heating surface inside the air passages.

Although recuperators invoke considerable fuel savings, their practical use has been rather limited since, in high-temperature work, metallic recuperators burn out unless they are made of expensive heat-resisting alloys or unless expensive means of temperature control are installed. Tile recuperators always leak — sooner or later.

The amount of leakage occurring in a tile recuperator can be determined if the quantities of air entering and leaving can be metered accurately. Both the quantity and the location of the leaks should be determined.

In most designs of recuperators, air leaks out of the air passages and finds its way into the gas passages. The best procedure is to take samples of the gases where they enter the recuperator (in various passes and at the outlet) and then make Orsat analyses of the samples. If the carbon dioxide decreases and the oxygen increases from one sample to the next, a leak exists between the points at which the two samples were taken.

In order to estimate the effect of uniformly distributed leaks, it is customary to assume that all leakage occurs at the hot end of the air passage where it would do the greatest harm. The leak causes an insufficient volume of air to flow to the furnace, and the fan must be speeded up to restore the supply. More air than intended is heated on the original heating surface, and the temperature — as well as the radiating capacity of the hot flue gas — is lowered by dilution with air. If a concentrated leak causes the preheating to be (x) degrees lower than it would be in a tight recuperator, it is common practice to assume that, with uniformly distributed leaks, the preheating is lowered 1/2 (x) degrees.

Another reason for the somewhat limited use of recuperators lies in the working cycle of many heating operations. In annealing, for instance, furnace and charge are heated and cooled together. A recuperator would save heat during so small a fraction of the cycle that it is usually omitted.

Many installed recuperators are not kept in use because they are not easily accessible for repairs, replacement, and cleaning.

Regenerators were originally designed for the purpose of raising flame temperatures to high levels — not for the purpose of heat salvage — so that many industrial processes requiring very high temperatures could be performed. Regenerative furnaces have very limited use in industrial heating.

In addition to the furnace itself, much floor space is required by the reversing valves and the stack. The regenerators, which necessarily are below the furnace, must be made accessible for inspection and repair. This requires either a deep excavation or a very high furnace floor. There are practically no small regenerative furnaces in use, since a regenerative furnace is not portable and regular reversing requires attention. This type of furnace cannot be moved with ease because it needs a tall stack and becomes part of the building. Instead of fitting into the natural course of manufacturing operations, those manufacturing operations must frequently be changed to suit the furnace. Its use is limited to melting glass and steel, heating large forgings, and forging ingots and other irreuglar pieces of varying size that cannot be pushed through a continuous furnace. Recuperators will eventually replace regenerators, except where the recuperator may become clogged because of the nature of the combustion products.

Important relations exist between size of furnace and regenerator, time between reversals, thickness of brick, conductivity of brick, and heat-storage ratio of brick. In order to understand these relations, it is advisable to follow the events that occur during reversal (Figure 12). At the time of reversal, the combustion products in the flue, regenerator, and uptake must pass the burner before preheated air is ready to sustain combustion in front of the burner. The time required for this process is the sum of the durations required for throwing the valve, bringing the moving column of combustion products to rest, starting them in the opposite direction, and passing them up to the burner. Some mixing of waste products and incoming air consumes 5 to 30 seconds, depending on the size of the regenerator.

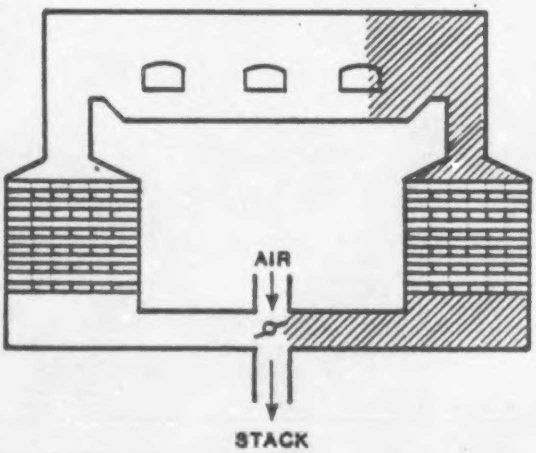


Figure 12. Events at Time of Reversal.

During part of the time, a mixture of waste gases and air sweeps over the hearth of the furnace, producing oxidation. In furnaces fired with producer gas and those in which both air and gas are regenerated, an additional delay is caused by the escape of at least the capacity of one regenerator of gas to the stack at each reversal; moreover, too frequent reversals distract the attention of the operator from other equally important work, unless the reversing is done automatically by a clock.

On the other hand, long periods between reversals necessitate a great weight of brickwork in the checker because of the great quantity of heat that must be stored between reversals. This results in larger regenerators and in greater first cost. Furthermore, long periods of reversals result in lower average temperature of preheating and, consequently, in reduced fuel economy.

Since there are arguments in favor of both short and long periods of reversal, it follows that there will be a most favorable period for each furnace. A considerable departure on either side from that period will produce a change in fuel economy. The result is that a great variety of reversal periods are found in practice: four-door furnaces, such as are used in rolling mills, use five minutes; in blast-furnace stoves, the time between reversals is much longer. Moreover, the gas period and the air period are different.

Accumulation of dust on the bricks and slagging of the brick surfaces cause the efficiency of heat transfer to decrease as the furnace becomes old. No definite information is available on the conductivity of dust deposits; in any case, the effect of such deposits must depend on their thickness. The overall coefficient may be reduced as much as 20% by the insulating action of dust deposits. Slagging, which occurs only on the upper courses of checker bricks, reduces the capacity of the surface for absorbing radiation. The few data available seem to show that gas radiation may be reduced 10% by slagging, resulting in a reduction of 9% in the overall coefficient.

Horizontal-flow checkers are always much less efficient than the vertical-flow type. The hot gases hug the top of the checker and, after reversal, most of the cold air passes along the lower part of the checker — little of it comes in contact with the bricks that have been heated by the gases. The importance of preheating air leakage into checker chambers, and especially into the downtakes, is obvious. The air cannot possibly be heated to a higher temperature than that at which the gases enter the checker, no matter how much checkerwork is provided or how efficient it is.

In heating furnaces, there is no reason why the downtakes should not be insulated. Insulation of the checker chamber proper saves energy by reducing the heat conducted through the wall and, to a greater extent, by preventing infiltration of cold air. Modern regenerators are usually either encased in an airtight steel shell or coated outside with a sealing cement.

Waste-Heat Boilers

The third method of utilizing the heat of combustion products is the generation of steam through waste-heat boilers. The amount of steam that can be generated from a given furnace depends on the weight of the flue gases in unit time, their temperature at entrance to the boiler, and the temperature to which they can be cooled. The temperature of the gases at entrance to the boiler should be approximately equal to the furnace temperature, except when the boiler is used in connection with a continuous furnace. In this case, the flue-gas temperature depends on the heating rate. In heating-furnace practice, waste-heat boilers are practically never used if the furnace is equipped with either a regenerator or a recuperator.

The flue-gas flow depends on the heat requirements of the furnace and its temperature. The temperature of the hot flue gases entering the boiler may slightly exceed the temperature of the furnace if the boiler is mounted immediately above the furnace and is connected to the furnace by a very short flue. The flue gases will be cooler than the furnace if the boiler is set some distance away from the furnace. The temperature of the stack gases at the boiler exit depends on the rate of gas flow, temperature of entering gases, heating surface of boiler, steam and water temperature, and coefficient of heat transmission. The heat transfer coefficient varies with the velocity of the gases, the cleanliness of the boiler surface inside and out, and the arrangement of the passes.

Much waste heat is available from 2200°F furnaces; a comparatively small amount is available from 1400°F to 1600°F furnaces, unless fan draft is used and the gases are cooled to a low temperature. To make the installation a success, several precautions must be observed in the design and operation of the combined furnace and waste-heat boiler. The furnace doors must be designed so that they are reasonably tight. If the doors are poorly fitted, broken, or partly open, a large quantity of flue gas is discharged into the building. Furthermore, the furnace proper must be shut tightly at all times. If doors must be open because large ingots project into the room, the openings around the ingots should be filled with brick and fireclay. The flue leading from the furnace to the boiler must be made as short and direct as possible. A long flue causes temperature loss or draft loss, and usually both. A long flue also makes it difficult to start the furnace and boiler, such as an auxiliary grate or an oil or gas burner.

It seldom pays to attach a waste-heat boiler to a single in-and-out furnace, because of the intermittent operation of the furnace. Forge furnaces are cooled between successive ingots and discharge fairly cool combustion products after charging of a fresh ingot; during the soaking period, the firing rate is reduced. The same is true of mill furnaces. For this reason, two or three furnaces frequently discharge their combustion products through one waste-heat boiler. This combination is quite popular for small forge plants or for small mills in which the one waste-heat boiler furnishes the only source of steam and power.

The fire-tube boiler is not suitable for installations where the temperatures vary rapdily, because tube leads develop; nor is it desirable where the feedwater is very bad, because of the difficulty of removing scale. In such cases, water-tube boilers are used. The two types have been found to have about the same efficiency of heat recovery when the gases are above 1800°F.

Recovery of waste heat from industrial furnaces, when properly applied, can provide very attractive reductions in total fuel consumption. However, the design and installation of recuperators, regenerators, and waste-heat boilers require specialized engineering experience to ensure safe, efficient operation.

FUEL SAVING IN OPEN-HEARTH FURNACES

The following discussion was designed for practical guidance in the operation of hearth furnaces – in particular for steel making – but has a general bearing on all types of regenerative hearth furnaces.

The problem of saving fuel in open-hearth furnace practice is inseparable from problems of steel output and refractory consumption. However, in addition to alterations in furnace design and construction, there are points to be noted in practice that tend to reduce the fuel consumption without adversely affecting output or wear of brickwork and may benefit either or both. A number of these are set out below.

- Gas pressure should be kept at the pressure consistent with the required output rate for optimum working.
- Culverts, valves, and furnace brickwork from producers to gas ports should be examined regularly and repaired when necessary. There should be no leakage at these places.
- Combustion in the furnace needs special consideration. Correct mixture of gas and air is essential to give the maximum heat to the bath. If the air and gas are not measured, or the ratio of air to gas is not indicated on an instrument, the flame should be closely watched. It should be highly luminous and not unduly long; the tip should on no account reach the outgoing block; and it should give the maximum practicable coverage of the hearth. Too long a flame results in damage to the outgoing ports and tends to overheat slag pockets and checkers.
- A slight pressure, but not an over-pressure, should be kept up in the furnace. A slight pressure prevents excessive cold air from being drawn in and saves the amount of fuel necessary to heat the air to furnace temperature. An over-pressure forces too much flame through openings in the furnace structure, wasting heat outside the furnace and damaging structural steel and brickwork. Normally, a slight flicker of flame visible

at the doors is an indication of correct pressure. Dampers are arranged to work easily and should be adjusted according to the amount of gas being burned. The more gas used, the greater the quantity of waste gases formed and, consequently, the wider the damper must be opened to give the extra draft required to clear the furnace.

- Gas ports and slopes should be fettled frequently in order to maintain correct alignment and frame direction.

- Reversals should normally be made at regular intervals, although this procedure should be modified if the checker temperatures have become unbalanced. The objective is even heating across the bath. This is much easier to attain if the corresponding checkers at each end of the furnace are approximately equal in temperature. Temperature recorders and controllers installed in the system greatly assist the melter in balancing operations.

- As much information as possible relating to the draft in the furnace systems should be obtained if the pressures and drafts are known at various points when the furnace is not going well. For this purpose, holes should be cut through the brickwork and fitted with easily removable plugs. Readings with a draft gauge may then be taken regularly. Suitable points for the test holes are in gas and air uptakes (a foot or so above stage level); in gas and air slag pockets; above gas and air checkers; in gas and air culverts as near base of checkers as practicable; in the stack flue near the damper and on the furnace side of the damper; and before and after the main gas valve, for obtaining drop in pressure across the valve. If the difference between the pressures before and after the main gas valve is higher than usual, the gas flow through the valve is being impeded and the valve housing needs inspection and clearing. If the difference between the waste gas drafts taken above and below a set of checkers is greater than usual, the checkers are becoming choked.

- CO_2 recorders are of doubtful value when applied to the waste gases of an open-hearth furnace. Analyses should be made to check correctness of combustion and incidence of air leakage. If, about an hour after the furnace has been fully charged, Orsat samples are taken through a silica tube inserted into the gas downtake, reliable figures can be obtained. Normal CO_2 content at this point is 15-16% when operating on producer gas. Care must be taken that no air is drawn into the uptake around the silica tube.

- Instruments to record drafts and pressures continuously are very useful, especially when simultaneous readings taken at two or more points are necessary for accurate comparison. For a permanent installation, it is preferable to have a limited number of recorders, including one showing the gas pressure and another showing the effective stack draft. A multitude of recorders would confuse rather than inform. A modern furnace could have an automatic control system, which might render all these provisions necessary. In effect, in one and the same composite system, it would control the rate of fuel input into the optimum value and regulate the air-to-fuel ratio, temperature, and draft to give the desired conditions automatically. When instruments fail, field survey methods must be called into service.

EXERCISES

1. List the major types of baking ovens and give a brief description of each.
2. There are three operational controls that can affect the amount of energy used to bake a particular product. Discuss how the controls could be adjusted to conserve energy without reducing product quality.
3. With the concept of heat balance in mind, complete the following data and then put them into the form of an energy diagram.

Energy Loss:	To exhaust	70%
	To band	5%
	To product	10%

4. Discuss the relationship of excess air to oven burner efficiency.
5. Discuss the process accomplished in recuperators and regenerators. Compare and contrast the equipment involved.
6. Outline the auditor's approach to the process energy audit. (Compare and contrast the process energy audit with other types of audits covered in the Energy Audits course modules.)

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TEST

Enter true or false in the blank at the end of Statements 1-6.

1. A burner operating at 50% excess air uses 30% more fuel than one operating at 20% excess air. __________
2. Preheating combustion air for furnaces that use quick-burning fuels is advantageous. _________
3. It is possible to conserve energy in baking ovens without altering baking temperature or baking time. ________
4. Recuperation and regeneration are two names for what is essentially the same process. ________
5. To maximize fuel efficiency in hearth furnaces, a slight underpressure should be maintained within the furnace.

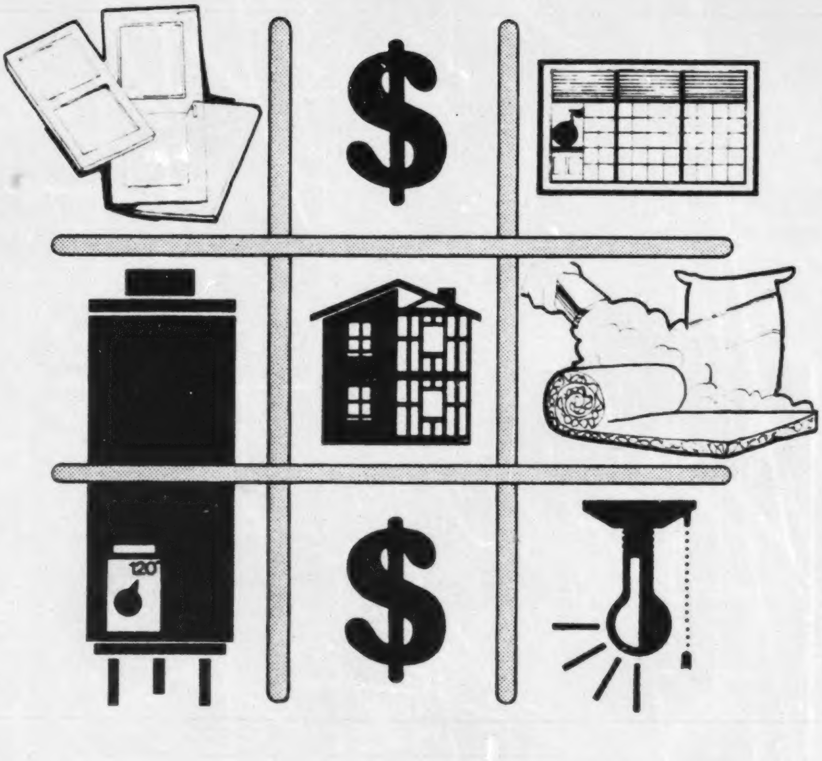
   ____
6. Negative air pressure in a bakery can result from the use of an atmospheric burner system. __________
7. Match items from Column B with those in Column A. Enter answers in the blanks beside each item in Column A. There may be more than one answer for each question.

	Column A		Column B
_____	Operational control	a.	Radiant
_____	Heat balance	b.	Pressure
_____	Indirect-fired	c.	Sankey diagram
_____	Waste heat boiler	d.	Zone temperature
_____	Direct fired	e.	Recuperator
_____	Stack loss	f.	Heat exchanger
_____	Regenerator	g.	Batch type
_____	Hearth furnace	h.	Flue gas
_____	Baking oven	i.	Convective
		j.	Heat transfer
		k.	Steam generation
		l.	Reversal

ENERGY TECHNOLOGY

CONSERVATION AND USE

ENERGY AUDITS



MODULE EA-10

APPLICATIONS OF SOLAR ENERGY

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

This module specifically emphasizes the essential qualities of technically and economically feasible solar applications. Types of solar energy systems are discussed, as well as their characteristics and application considerations. The energy auditor will determine whether current renewable resource technology has potential for cost effective application in a particular facility.

PREREQUISITES

The student should have completed Module EA-09, "Process Energy Systems."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Describe and contrast types of solar systems and define basic terms.
2. Discuss heating through passive design.
3. Discuss active solar heating systems.
4. Describe the domestic water heating process.
5. Discuss and compare air and liquid transfer systems.
6. Discuss distribution systems.

ALTERNATIVE RESOURCES: HISTORIC AND ECONOMIC PERSPECTIVE

Until quite recently, low energy costs have encouraged the design of buildings that meet their energy requirements almost exclusively with "traditional" or non-renewable sources of energy. The traditional energy sources for existing buildings are (1) electricity, generated off-site by a utility company and distributed to the building, and (2) fossil fuels, such as oil, gas, coal, and methane, which are delivered in storable quantities (with the exception of natural gas) and burned at the building site.

Alternative or "renewable" energy sources include the following:

- Solar energy for heating, cooling, and electric power generation
- Total energy systems
- Wind energy
- Fuel cells
- Geothermal energy
- Nuclear power
- Methane gas generated from liquid wastes
- Solid waste
- Tidal power
- Hydropower
- Ocean thermal differences
- Coal gasification
- Hydrogen from the electrolysis of sea water

Rising fuel costs and the development of alternative resource technology have begun to make some of the alternative resources economically viable as options in both the design of new buildings and the energy efficiency modification of existing buildings.

This module covers the use of solar energy for water heating and space heating and cooling, since these technologies are most readily useful for the energy auditor. This is because (1) the technologies are well-known; (2) expertise for design and installation is available; (3) installation and operating costs can be estimated from available data; (4) each system is compatible with energy conservation measures discussed in other modules; and (5) hardware is commercially available. Thus, the energy auditor has access to equipment and information which can demonstrate – in terms of predictable cost and energy savings – the effectiveness of these solar energy systems.

Solar energy reduces the need for significant quantities of conventional energy used to run a building's environmental control system. Solar energy systems reduce air pollution and operating costs, save fossil fuels, and can be effectively used together in the same building.

Other alternative energy sources are not included in this module due to one or more of the following factors: (1) hardware is not commercially available, nor are the future requirements for hardware sufficiently identified; (2) electric power from alternative sources can be substituted in the future for conventionally-generated electric power, and no provisions for building modification are required now; or (3) expertise is not available to design such systems.

Engineering feasibility studies of alternative energy systems other than solar systems can be performed only by qualified consultants who can select equipment for analysis, estimate costs, and predict the annual performance over a 20-year period. Because the initial investment in these systems is significantly higher than for conventional systems, special care is necessary to ensure that the life-cycle cost economics are accurately determined.

APPLICATION OF SOLAR ENERGY

Currently, the most common solar uses have been solar water and space heating. Solar heating systems are generally grouped into two categories: active and passive. The system type employed depends on the method used to collect, store, and distribute solar heat within the building. Some systems are designed solely for space heating; others are designed for both space and domestic water heating. Frequently, it is more cost effective to integrate space and service water heating into one system, because the collectors and storage unit can then be used year round to provide space heating and hot water in the winter and hot water in the summer.

Active systems rely on pumps or blowers to transport solar heat from the collectors to the storage unit, or directly to the rooms of the building. Passive designs incorporate collectors (windows) and storage (walls) into integrated elements located in, or adjacent to, the occupied space. These elements may involve specially designed walls that absorb heat, or the element may be part of the building structure. In buildings with passive systems, stored heat is supplied to the rooms by radiation or natural convection.

Both active and passive designs are suitable for residential or light commercial buildings. Neither system can economically supply all heating needs in the building. Although systems are usually separated into passive or active types, "hybrid" systems, which incorporate elements of both, have been designed to utilize solar energy to the greatest advantage for heating space and providing hot water.

Other applications of solar energy include the following:

- Tempering heavy oil: For large installations with #6 oil, flat plate solar collectors can be effectively used to preheat oil before combustion. The oil storage tanks can be fitted with heating coils through which the heated fluid from the collector is circulated. No additional storage system is required.
- Tempering combustion air: The efficiency of oil or gas combustion increases as the temperature of combustion air is increased. Solar air or water collectors, without any additional storage facilities, can be used to temper air for combustion. In the same manner, they are used to temper make-up air for ventilation.
- Electric power: The technology for using solar energy for the direct generation of electric power with photovoltaic cells is well-known, i.e., in the space program. In remote areas of the world, solar cells are used to generate small quantities of electricity primarily for signal purposes. In Delaware, there is a house equipped with solar cells to supply electrical energy and most of the annual requirements for thermal energy. The hardware available for buildings is limited and too costly to consider at the present time. The area required for solar collectors for heating and cooling will be ample to accommodate the future installation of solar cells for power generation.

Solar energy can also be used to generate high-temperature hot water or steam, which can power a turbine or heat-actuated engine for power generation. However, these systems are not commercially available, and the costs are not comparable with conventional generating methods.

SOLAR COLLECTORS AND EXISTING HEAT SYSTEMS

Solar collectors convert direct and diffuse radiation from the sun into heat. They are manufactured with one or two cover plates, a metallic absorber plate with an absorbing or selective surface, back insulation, side insulation, and an enclosing frame (Figure 1). Information on features and performance of collectors is available from the manufacturers. When selecting a solar collector system, it is necessary to consider thermal performance, capacity, and durability.

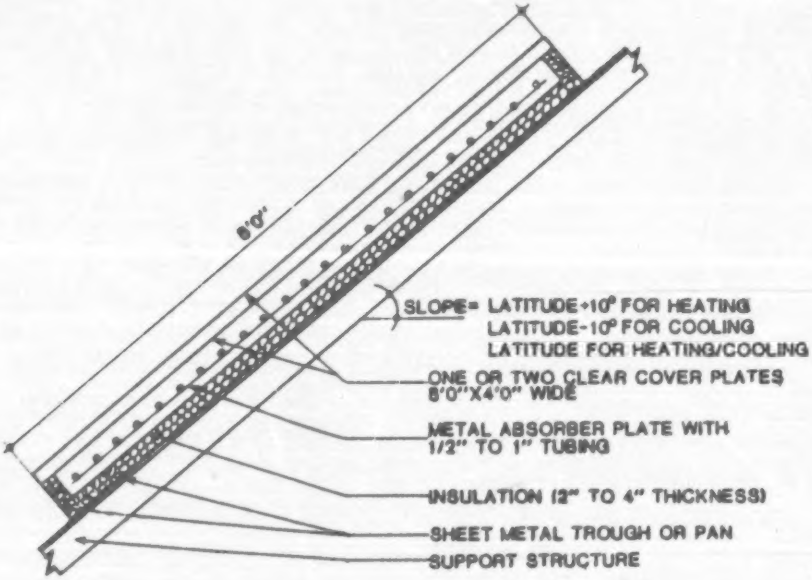

8'0"
SLOPE= LATITUDE+10° FOR HEATING
LATITUDE-10° FOR COOLING
LATITUDE FOR HEATING/COOLING
ONE OR TWO CLEAR COVER PLATES
8'0"X4'0" WIDE
METAL ABSORBER PLATE WITH
1/2" TO 1" TUBING
INSULATION (2" TO 4" THICKNESS)
SHEET METAL TROUGH OR PAN
SUPPORT STRUCTURE

Figure 1. Solar Collector and Cross Section.

Collectors can be located on a building roof, on an adjacent building or garage, or on the ground. If a building is being modified, provisions for a solar collector system should be made at this time in order to ease future installations. For example, the entire south wall can often be used as a collector if it is designed with that conception in mind.

The size of the collector varies with use, climate, and the HVAC system with which it operates. The collector area required for heating ranges from 20% to 50% of the total building floor area in order to provide 20% to 70% of the annual heating and/or cooling energy requirements.

Flat plate collectors absorb both diffuse and direct radiation. Depending on their construction and meteorological and climatic conditions, each square foot of collector can collect from 50,000 to 150,000 Btus per heating season. Reflectors increase the capacity from 15% to 25% at relatively low installation costs. The efficiency of the collector is directly proportional to the collection temperature. Characteristics of the heating system, in the building that interfaces with the solar collector and storage units, have a major influence on the overall economic feasibility of the complete system. The optimum tilt for collectors used solely for heating and domestic hot water is latitude plus 15°. Any variations in tilt should be toward a steeper angle rather than a flatter one. Orientation should be 5°-10° west of due south, but not more than 10° variation either side of this azimuth. A larger variation will require more collector area for the same thermal performance.

With water-type collectors, the higher the temperatures required, the greater the benefits of absorber plates with selective surfaces. Absorptive surfaces – flat black, green, or even dark red – have an absorption coefficient of 0.9 to 0.95, but all have the same emmissivity. A selective surface can have approximately the same absorption rate as other absorptive surfaces, but it must have an emission rate of only about 10% to 15% of the radiation it receives. In many cases, only one layer of glass or plastic will be required when selective surfaces are used – two might otherwise be required.

Air heating collectors are most suitable for space heating applications (when cooling is not being considered) and for relatively small buildings. Except for buildings of less than 2,000 square feet in area, few air collectors are commercially available; however, they can be specially designed for larger buildings. Air collectors are particularly applicable for tempering make-up air or outdoor air for ventilation. In many cases, no storage systems will be required for tempering ventilation air when the load exceeds the collector area for five days per week. Most applications using air collectors will be at lower temperatures than those of water-type collectors. When air collectors are well-designed, selective surfaces are not necessary.

The total cost/benefits of the collector and storage system – and the heating system with which they interface – must be analyzed for each of the major variations in the collector design and installation to optimize economic feasibility.

In recommending the installation of solar collectors, the auditor should consider the following:

1. Adequate support must be provided to carry the dead weight (12 lb/ft^3) of the collector plus wind loading.
2. If possible, the collector should be oriented 10° west of due south. For practical purposes, collector performance will be adequate if orientation is within 20° either side of due south. Orientation further east or west will require additional collector area.
3. If the collector is used solely to supply hot water, a fixed tilt of latitude plus 10° will usually be optimal – variations of 10° up or down will not seriously affect yearly performance.

4. If the collector is shaded more than 10% of the time, a larger collector will be necessary.
5. For each 16 gallons of hot water used per week, approximately one square foot of collector area and one gallon of hot water storage capacity in use must be provided. If the facility has kitchens or other processes that require water at elevated temperatures, the collector area should be approximately one square foot per 20 gallons of hot water used per year.
6. The existing domestic hot water heating system, even though inefficient or undersized, will usually be adequate to provide heat to supplement the solar collector system.

(NOTE: These are general provisions – not design standards. Each installation must be examined individually.)

Figure 2 shows one of many possible solar collector configurations. This system was installed on the roof of a federal office building in Manchester, New Hampshire.

The existing heating and cooling system influences the size and type of solar collector system. Existing radiation, fan coil, or induction units, sized to handle the average peak heating load with electricity, steam, or water above 180°F, limit the hours of useful collection unless the heating system is modified by one of the following methods:

- Replacement of some or all of the existing terminal units with oversized fan coil units that can operate with water at a lower temperature (approximately 120°F).
- Addition of an air handling unit with oversized fan and coils to supply part, or all, of the areas to be heated.
- Addition of radiant heating coils.
- Addition of new heating coils to existing air handling units or forced air furnaces.

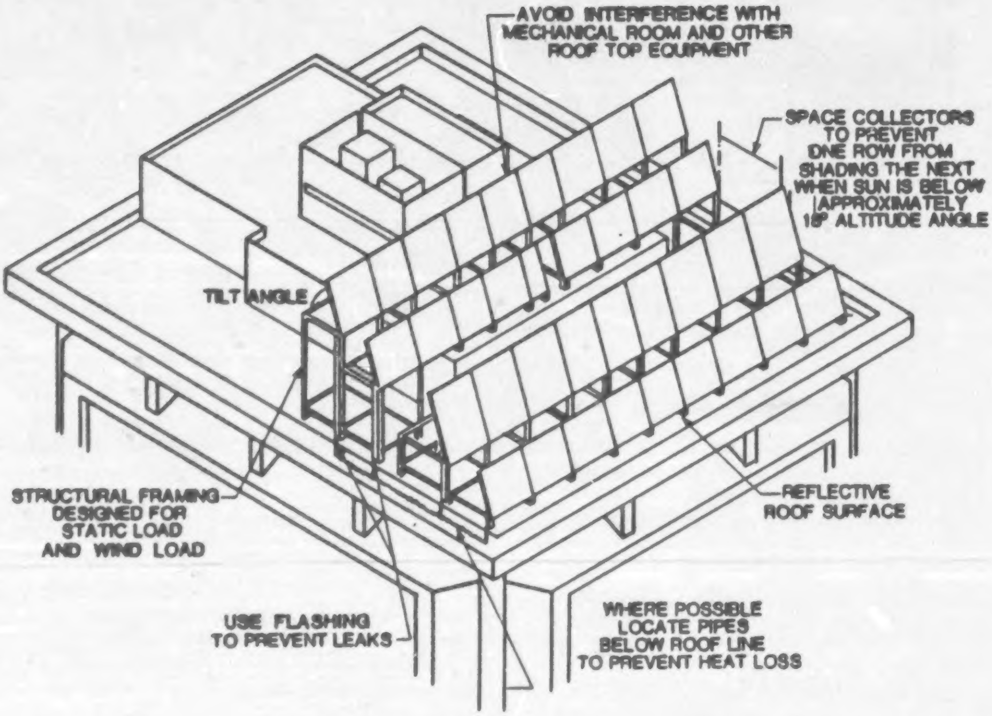

AVOID INTERFERENCE WITH MECHANICAL ROOM AND OTHER ROOF TOP EQUIPMENT
SPACE COLLECTORS TO PREVENT ONE ROW FROM SHADING THE NEXT WHEN SUN IS BELOW APPROXIMATELY 18° ALTITUDE ANGLE
TILT ANGLE
STRUCTURAL FRAMING DESIGNED FOR STATIC LOAD AND WIND LOAD
REFLECTIVE ROOF SURFACE
USE FLASHING TO PREVENT LEAKS
WHERE POSSIBLE LOCATE PIPES BELOW ROOF LINE TO PREVENT HEAT LOSS

Figure 2. Solar Collector Layout.

Radiant hot water panels, furnaces, or air handling units are the forms of heating that are most compatible with solar energy heating systems, since they can either use the same coils or be fitted with new ones to accommodate the lower collector water temperatures.

Solar collectors combined with existing or new heat pumps can be very effective. Low temperature fluid delivered from the collector in cold and overcast weather serves as a heat source for a heat pump. The heat pump boosts the temperature to a higher level and the useful hours of solar energy collection are substantially increased. Solar-assist heat pump installations should be considered, especially in existing buildings that are already equipped with heat pumps or with electrically-driven chillers that can be converted to heat pumps.

COOLING AND DEHUMIDIFICATION

The common means for utilizing solar energy for cooling and dehumidification are with absorption chillers, or with desiccant systems for dehumidification.

With absorption systems, the heated fluid serves as the heat source in the absorption generator. Most existing units require 230° to 270° for generation, and solar collectors on the market cannot provide those temperatures for any appreciable lengths of time. However, newer low temperature absorption units are now available in limited sizes, which can operate at generator temperatures as low as 180°F with only a slight loss of rated capacity.

Flat plate collectors with selective surfaces and supplementary reflectors can operate at temperatures up to 200° in some climatic zones for a sufficient number of hours per cooling season to operate absorption units at high capacity. However, there are not many areas in the country where absorption units operating from solar collected heat alone can supply even 50% of the yearly cooling requirements of the building.

For cooling alone, the tilt of the collector should be equal to latitude less 10°. Where the collector is used for both heating and cooling, the heating efficiency suffers if the angle is adjusted for cooling. A detailed analysis is required to determine optimum tilt angles of the collector for year-round use.

There will be very few situations where solar cooling will be economic until the collector performances are improved and/or absorption units are produced that will operate at 160° to 180°F generator temperatures. Both developments appear to be imminent.

REGENERATING DESICCANTS WITH SOLAR HEAT

Regenerating desiccants with solar heat is proving to be very cost effective. In areas where evaporative cooling is presently impractical because of high relative humidity, evaporative cooling combined with desiccant dehumidification can provide adequate comfort. Heat from the solar collector can supplement heat from other sources to regenerate the desiccant. Since regeneration temperatures are lower than those required for absorption cooling, the collector is more cost effective than with the absorption unit.

ESTIMATED COSTS

Costs and collector performance are continually changing. For new buildings, estimates should be based on preliminary design concepts and layouts. When retrofitting an existing building, manufacturers and contractors should be contacted only after the energy auditor has determined that a facility has definite potential for using an active solar energy system.

ACTIVE SOLAR SYSTEMS

Typically, six components comprise the active solar heating system: the solar collector, the heat transfer medium, the heat storage unit, the heat distribution system, an auxiliary furnace, and control devices regulating heat collection, storage, and distribution. Many systems also include accessories for preheating domestic water.

THE HEATING PROCESS

Collectors may be fitted to the roof of the building, mounted on a stand, placed on the ground, or attached to the wall of the building. Placement of collectors depends primarily on convenience, economics, aesthetics, and access to the sun. Heat is transferred from the collector to storage either by air or by a liquid such as water or antifreeze solution.

If heat is transferred from the collector by air, the heat can be stored by heating rocks in a bin. If the heat is transferred by liquid, heat will be stored as hot water in an insulated tank. From storage, heat will be moved through conventional systems – such as hot water pipes of forced air ducts – to various points in the building. To regulate the flow of heat, automatic controls are provided to direct the position of valves or dampers at the command of temperature sensors in the system or the room thermostat. Figure 3 is a diagram of a combination domestic water and space heating system using air collectors.

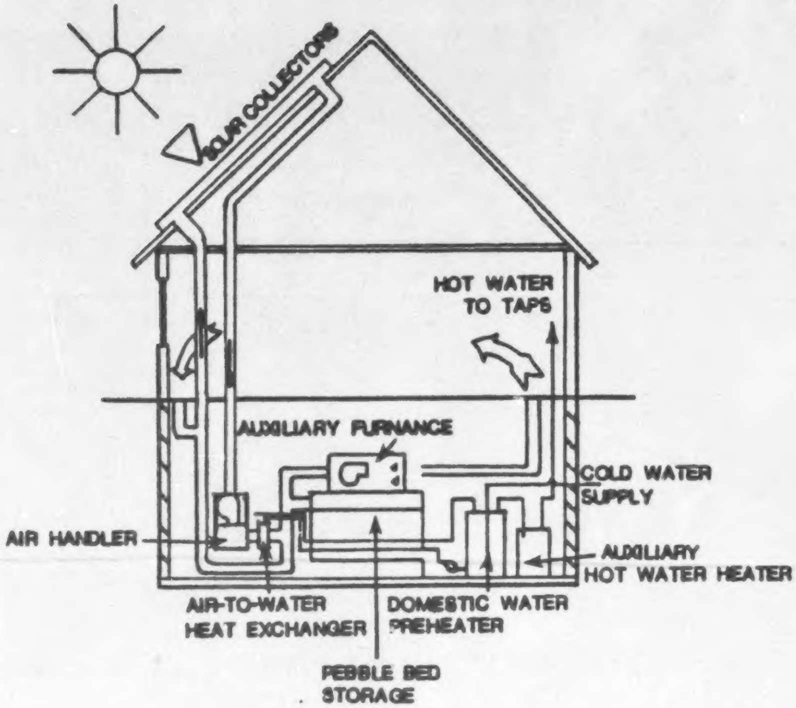

SOLAR COLLECTORS
HOT WATER TO TAPS
AUXILIARY FURNANCE
COLD WATER SUPPLY
AIR HANDLER
AUXILIARY HOT WATER HEATER
AIR-TO-WATER HEAT EXCHANGER
DOMESTIC WATER PREHEATER
PEBBLE BED STORAGE

Figure 3. Combination Domestic Water and Space Heating System Using Air Collectors.

The economical size of most solar heating systems is limited to provide heat for overnight use during a typical winter period with sunny days. On cloudy days there may not be enough solar heat collected to satisfy the heating requirements. Therefore, a conventional heating unit is required to ensure reliable heating regardless of weather.

Hardware

The hardware for solar space heating and cooling, as mentioned previously, includes solar collectors, piping, controls, and storage systems, which, in general, are similar in type to those used for heating domestic hot water. There are, however, the following notable differences:

- The required collector area and storage volumes must be larger and are more costly.
- Collectors must produce hotter water temperatures for space heating. Temperatures up to 180° are desirable, but lower temperatures can be used.
- The orientation of the collector is somewhat more critical.
- Absorber plates with selective surfaces rather than flat black coating will be more economically feasible for heating and cooling applications than for solar water heating alone.
- The interface with the existing heating and/or cooling system is critical.
- Storage systems must have a greater heat storage capacity per square foot of collector.
- Rocks or phase-changing salts can be used for thermal storage instead of water in some cases.
- Collectors can be air instead of liquid heating types in selected applications.
- A full-sized back-up heating system is required to supplement the solar system.

The cost of a solar system that provides 100% of the heating and/or cooling is prohibitive in most areas of the country — even more so for existing buildings than for new ones. However, in the existing heating system, burner/boiler or electric heat can be left intact (or modified as necessary) to supplement solar collectors.

Storage

The most practical storage system is hot water in metal or concrete tanks. From two to five gallons of storage are required per square foot of collector. The exact amount depends upon climatic conditions, the number of consecutive cloudy days, the type heating system, and the cost/benefits ratio of storage tank costs and collector performance versus the operating costs of the supplementary heating system. (Cooling with solar energy may affect the storage tank size.)

Since a supplementary heating system is required in virtually all cases, the costs of extra storage volume and space required can be offset on a life-cycle cost basis by operating the supplementary back-up system somewhat longer and reducing the volume of storage. Where the entry into a building is too small to deliver a tank, the tank can be fabricated by welding plates in the building, or it can be constructed of concrete. With hot air systems, rocks (approximately 100 lbs per square foot of collector) can be used for heat storage in place of water. Latent heat storage using phase-changing salts (salt hydrates, eutectic salts, and waxes and paraffins) requires less volume than water for equal thermal storage. The potential for the development of these storage types is very good, but at present they are not commercially available.

The tank and ducts, or piping from collector to the tank, should be insulated to limit thermal losses, at any storage or collection temperature, to 5% of system capacity per 24 hours. Sometimes the collector cannot deliver water at higher tank temperatures for periods of time. Therefore, a minimum of two storage tanks should be considered to permit storage of water at various temperature levels, so that the water temperature is not degraded by water at lower temperatures. With one tank only, collection is limited. Economic feasibility is also reduced since the collectors cannot be used to their maximum potential.

Controls

The control system must operate the circulating pump(s), divert warm water from one storage tank to another or direct to the load, and operate fans (in air system) to blow air through the collectors or storage in response to climatic conditions and building load. There are many variations in controls that are beyond the scope of this module. Controls are not a major cost of installation unless elaborate monitoring, data collection, and research are undertaken.

Antifreeze Protection

In areas where the outdoor temperature drops below 32°F, antifreeze protection is required for liquid flow collectors. The following systems may be used:

- A secondary circuit with an antifreeze solution (glycol, triethylene glycol, propylene glycol, or light oil with a heat exchanger and a separate pump).
- Draining the collector when outdoor temperature drops below freezing and refilling when temperature rises above freezing.
- A closed circuit drainage system with nitrogen as a purging agent.

- Bleeding a small amount of heated storage water through the collector in locations where temperatures drop below 32°F for only brief periods of time, and the days are warm and clear.

Each system has advantages and disadvantages. If the storage water bleed system shows only a small loss of thermal energy compared to useful heat collected on a seasonal basis (less than 5% loss), it is the least costly and least troublesome system.

The nitrogen system is still under development, and more data is required before it can be recommended without qualification.

Draining and refilling involve the problem of incomplete draining under some conditions and difficulties with venting when the system is refilled. Vents are also subject to freezing, which causes them to be inoperative.

The use of antifreeze with a secondary circuit introduces higher costs for the heat exchanger and secondary circuit, and corrosion is accelerated when antifreeze solutions reach high temperatures in the summer. However, most current installations use antifreeze with a secondary circuit and heat exchanger in cold climates.

AIR AND LIQUID SYSTEMS

Air and liquid systems have roughly comparable efficiencies in terms of the annual heat delivered per unit of collector area. When comparing the relative merits of each system type, it is wise to weigh all possible advantages and disadvantages in the context of climate, architecture, building site, expected maintenance costs, and the fraction of the building heating needs to be supplied by solar energy. Table 1 lists some advantages of liquid and air systems.

TABLE 1. ADVANTAGES OF LIQUID AND AIR SYSTEMS.

Liquid Systems	Air Systems
• Water and antifreeze are low-cost fluids with higher heat capacity than air.	• The collector fluid (air) will not freeze, boil, or cause damage by leaking.
• Storage volumes are relatively smaller than rock bins because water is an excellent heat storage material.	• Absorber plates, ducting, and other connections in air systems are much less susceptible to corrosion than their counterparts in liquid systems.
• Transport of heat over long distances in commercial buildings is less costly with water than with air.	• Pebbles in storage do not need to be replaced or specially treated.
• There is a large number of liquid-type collectors from which to choose.	• Solar-heated air can be circulated directly from the collectors to the rooms without the use of heat exchangers.
• Performance data on liquid systems are available.	• Maintenance requirements are minimal compared to liquid systems.

DOMESTIC HOT WATER GENERATION

Solar water heaters have been used throughout the world for more than 30 years, especially in Israel, Australia, Japan, and Florida. Although many solar water heaters are still in operation, numerous others were abandoned when repairs were required, because gas, oil, or electric heaters were more economical and energy was inexpensive. The high costs of fossil fuels and electricity have again awakened an interest in solar water heaters and other solar energy systems.

Solar water heaters may be economically feasible in office buildings and stores with 25 or more full-time employees. In religious buildings, the demand for hot water is insufficient to warrant purchasing a solar water heater, unless activities include extensive bi-weekly food preparation or school or office facilities in operation for more than 35 hours per week. When solar energy is economically feasible for space heating, heating domestic hot water with the same system will be economical, as well.

Solar water heaters are commercially available in the United States. The components are offered separately, or together in a complete package. They include a flat plate collector, storage tank (existing storage tanks can be used), piping, controls, circulating pump, and, in climates where the collector is subjected to freezing weather, a heat exchanger with a secondary pump, piping circuit, and antifreeze. Figure 4 shows a typical arrangement of the solar water heating system. System components and design considerations are discussed in detail later in this module.

For normal hot water use, approximately one square foot of collector per gallon of hot water used per day is adequate. If kitchens or other processes require hot water at elevated temperatures, an additional 25% to 50% of collector area is required.

The solar collector can be mounted on the main roof, on the roof of a building extension, or on the building site.

Generally, it is not feasible to provide 100% of the domestic hot water requirements with a solar system unless (1) the collector is also used for other services; (2) hot water temperature requirements do not exceed 90°F; (3) an existing storage tank is oversized for the building requirements; or (4) the building is located in a temperate or hot climatic zone.

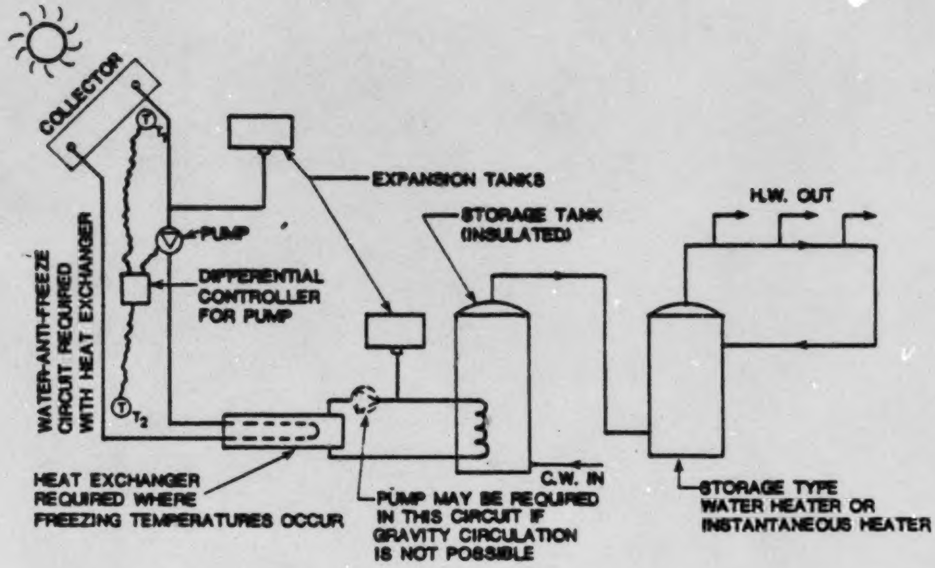

COLLECTOR
T_1
T_2
EXPANSION TANKS
H.W. OUT
STORAGE TANK (INSULATED)
PUMP
DIFFERENTIAL CONTROLLER FOR PUMP
WATER-ANTI-FREEZE CIRCUIT REQUIRED WITH HEAT EXCHANGER
HEAT EXCHANGER REQUIRED WHERE FREEZING TEMPERATURES OCCUR
C.W. IN
PUMP MAY BE REQUIRED IN THIS CIRCUIT IF GRAVITY CIRCULATION IS NOT POSSIBLE
STORAGE TYPE WATER HEATER OR INSTANTANEOUS HEATER

Figure 4. Solar Water Heating System.

SPACE HEATING AND COOLING

Prior to 1972, there were only about 20 solar heated buildings in the United States. Of those 20 buildings, only one was a commercial building; the rest were single family residences. Within the past eight years, there has been a proliferation of solar energy activity in the United States, resulting in hundreds of buildings now in design and/or under construction. While the majority of these are new buildings, the same design and construction techniques are frequently applicable to retrofitting existing buildings.

The National Science Foundation sponsored a program to retrofit four existing school buildings for solar heating. These installations are now providing valuable data on the performance of solar heating systems under varying climatic conditions. Also, under a National Science Foundation grant, solar collectors have been installed for heating and cooling an existing school building in Atlanta, Georgia.

Numerous other installations have already provided designers with guidelines, opportunities, and pitfalls to be avoided. This literature should be studied before a feasibility study of solar energy for heating and cooling is conducted.

PASSIVE SOLAR ENERGY SYSTEMS

In contrast to the active solar heating and cooling systems, passive solar systems collect and transport heat without mechanical assistance. Although passive systems are not as widely applicable as active systems (being limited to residential and small commercial facilities, for the most part), the energy auditor should be aware of the passive solar processes, the applicability of passive design, and the potential for integrating passive systems with active and/or conventional systems.

REQUIREMENTS AND CHARACTERISTICS

There are two basic requirements for passive solar design: (1) a south-facing wall for solar collection and (2) some form of thermal storage mass to absorb, store, and distribute the collected heat. The basic principle of passive systems is that energy flows from areas of higher concentration to areas of lower concentration. When the sun is shining, the storage mass has a lower energy concentration and, thus, absorbs energy. When the sun is not shining, the living space has a lower energy concentration, and the storage mass releases energy.

Passive systems are characterized by their simplicity of design, which means also that they are easy to operate and maintain. Since the technology of passive systems is not complex, they can be installed, operated, and maintained by personnel with limited technical background. Passive systems (1) are made of common construction materials, (2) usually last as long as the facility of which they are a part, (3) have few moving parts, (4) operate at low temperatures, (5) have no mechanical equipment (and thus no noise from mechanical equipment), and (6) are usually invisible from the interior of the building.

In addition to these advantages, passive solar systems typically add very little to initial construction costs, especially if masonry has already been selected as the construction material. Hence, in view of the large savings of heating energy, passive systems are economically justified in new buildings of the appropriate type. Determining the feasibility of retrofitting buildings with passive systems, however, is more complicated.

The single persistent problem with passive solar systems is that, since they are not mechanical, there is no way to control temperature variations within the narrow ranges that can be accomplished with either conventional systems or active systems. However, proper sizing and location of the thermal storage mass, windows, shading devices, and backup heating systems can compensate for this lack of control and make the passive system a viable alternative to mechanical systems.

The remainder of this module will be devoted to discussing the three major types of passive solar systems —

direct gain, indirect gain, and isolated gain – and what the energy auditor should consider before recommending them.

DIRECT GAIN SYSTEMS

In a direct gain system, the living space is heated directly by sunlight. To take advantage of direct solar gain, a building should have south-facing glass, which gets the maximum exposure to the sun in winter and the minimum exposure in summer. The floor and walls of the living space are constructed of material that is capable of storing heat.

Heat storage materials may be either masonry (concrete, concrete block, brick, stone, adobe) or water (in the form of a water wall). If masonry is the thermal storage material, from 1/2 to 2/3 of the interior surface should be exposed masonry. The water wall system – essentially a large metal or plastic container – requires that only one wall be covered with the thermal storage material. This wall must receive a maximum amount of direct sunlight in winter. Figures 5 and 6 compare the configuration of masonry and water thermal storage systems in a direct gain arrangement.

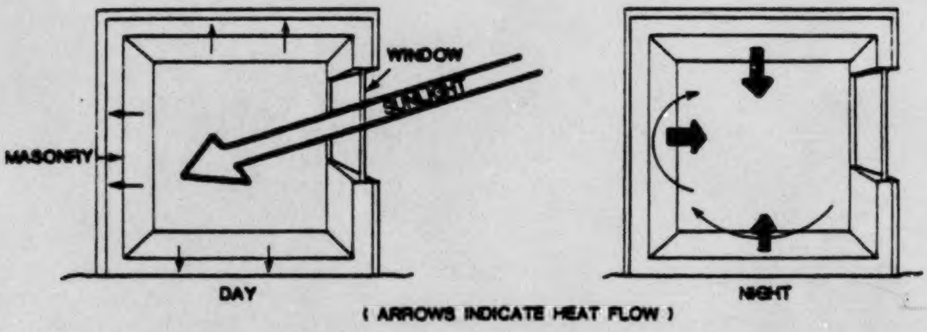


Figure 5. Masonry Thermal Storage Walls (Direct Gain).

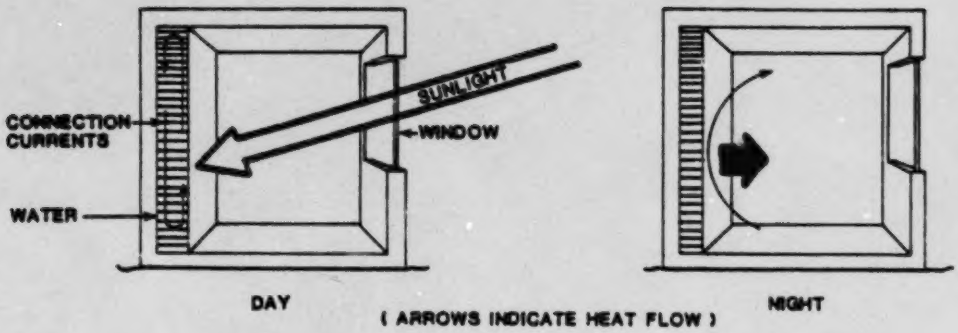


Figure 6. Water Thermal Storage Walls (Direct Gain).

Before recommending a direct gain system, the energy auditor should consider the following:

- Building configuration: The optimal building arrangement is an east to west linear extension, with the spaces that need heat aligned along the south wall.
- Collector glazing: Collector glazing should be oriented toward the south and designed to eliminate as much glare as possible.
- Construction and thermal storage materials: Masonry as thin as four inches can provide sufficient thermal storage capacity. In passive systems using water walls for thermal storage, the construction of all but the water wall can be of lightweight materials, such as wood.
- Thermal control: Depending upon the size and placement of windows and thermal mass and the color of the interior surfaces, temperatures can fluctuate from 10°F to 30°F. The temperature fluctuation can be controlled effectively through the use of shading devices, venting through open windows, and auxiliary exhaust fans. An added measure of control is obtained, of course, when a hybrid system – coupling a passive direct gain system with a conventional forced air heating system – is employed.
- Thermal efficiency: In winter, direct gain systems are 30% to 70% efficient; that is, most of the sunlight transmitted through the glazing is used for heating.

- Potential for retrofitting: Since direct gain systems depend upon the building's design and material, it is difficult to fit them to existing buildings unless the existing buildings have exposed masonry walls and floors and a clear southern exposure.

Direct gain passive solar systems depend upon decisions which are made during the design stages of building. Since they are made of the same materials used in conventional masonry construction, direct gain systems can frequently be incorporated into buildings at little or no additional cost.

INDIRECT GAIN SYSTEMS

Although the same basic principle of heat flow underlies both the direct and indirect gain systems, the thermal mass in the indirect system is located between the sun and the space to be heated. Again, the thermal storage masses are typically masonry or water, although they are found in different configurations in indirect gain systems.

The masonry thermal storage wall faces south, is usually painted black or some dark color, and is covered with glazing (usually double). Light passing through the glazing is absorbed as heat radiation by the outside face of the wall, and heat is then conducted through the wall to the space to be heated.

As shown in Figure 7, vents placed at the top and bottom of the thermal storage wall can take advantage of natural convection, or thermocirculation. As the air between the wall and the glazing heats up, it rises, entering the living space through the upper vents and drawing cool air through the lower vents. Dampers over the vents can be closed when thermocirculation is not desirable.

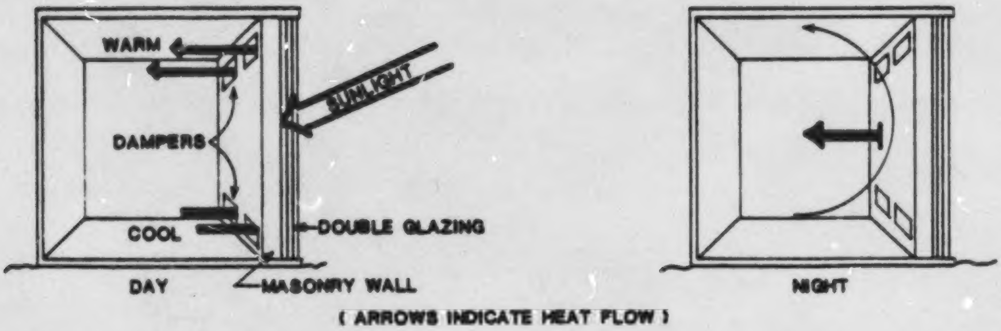

WARM
DAMPERS
SUNLIGHT
COOL
DOUBLE GLAZING
DAY
MASONRY WALL
NIGHT
(ARROWS INDICATE HEAT FLOW)

Figure 7. Masonry Thermal Storage Wall (Indirect Gain).

In an indirect gain system, the water wall functions in much the same way as the masonry wall, except that heat is transferred to the living space by convection currents in the water rather than by conduction. As energy is absorbed by the black exterior face of the water wall, the temperature of the water rises, inducing convection currents inside. These currents keep the surface relatively cool and distribute the heat evenly throughout the entire water (thermal storage) volume. Figures 7 and 8 compare the masonry and water thermal storage walls.

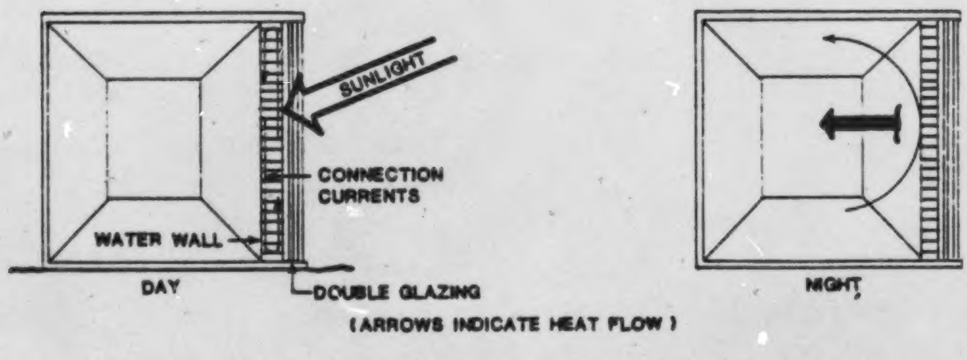

SUNLIGHT
CONNECTION CURRENTS
WATER WALL
DAY
DOUBLE GLAZING
NIGHT
(ARROWS INDICATE HEAT FLOW)

Figure 8. Water Storage Wall.

Before recommending a thermal storage wall system, the energy auditor should consider the following:

- Building configuration: The depth of the space to be heated is limited, by the maximum distance for radiant heating, to 15-20 feet. Thus, the optimum arrangement of spaces to be heated is a linear one, extending east to west, with an extensive southern exposure.

- Collector glazing: Since the thermal storage wall is located between the sun and the space to be heated, the collector glass does not admit any light into the living space (unlike the glass in direct gain systems). However, windows can be incorporated in the thermal storage wall, which will both admit some light and provide for some direct heat gain.

- Construction and thermal storage material: Since all of the thermal storage mass is in the masonry or water of the wall, there are no restrictions on the materials or finishes used on the remaining interior surfaces.

- Thermal control: Temperature fluctuations can be controlled to a great extent by careful calculation of wall thickness. Heat output can be regulated by thermocirculation vents with dampers or insulation panels or drapes, which can be easily positioned and removed from the wall's interior surface.

- Thermal efficiency: Thermal wall systems have an efficiency of 30% to 40%, which is comparable to that of many active solar heating systems. Water proves to be a slightly more efficient storage medium than masonry when systems of equal wall area and storage capacity are compared.

- Potential for retrofitting: It is relatively easy to add a thermal storage wall to the southern side of a structure that has a clear southern exposure.

Thermal storage wall systems allow for a wide variety of construction materials and interior finishes and provide a high degree of control over indoor temperatures.

ATTACHED GREENHOUSE

The attached greenhouse is actually a combination of direct and indirect gain passive systems. The greenhouse or sunroom is located on the south side of the building, and separated from the living space by a thermal storage mass – usually a masonry or water wall. Thus, the greenhouse is heated by direct gain and the living space is heated by indirect gain. Figure 9 shows a typical attached greenhouse arrangement, and also shows how vents can be located in the thermal storage wall to permit thermocirculation similar to that achieved in the indirect gain, masonry wall system.

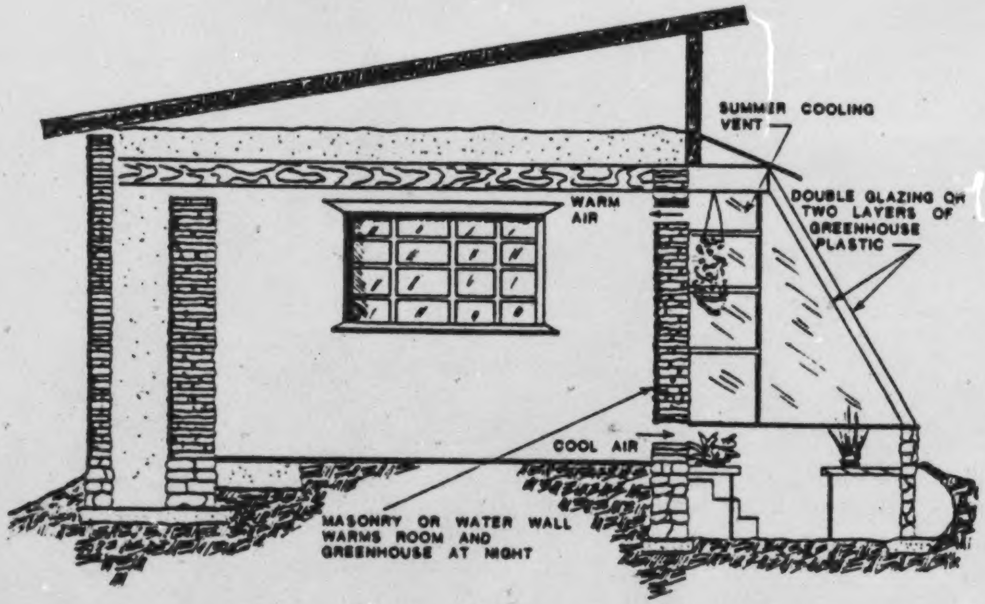

SUMMER COOLING VENT
WARM AIR
DOUBLE GLAZING OR TWO LAYERS OF GREENHOUSE PLASTIC
COOL AIR
MASONRY OR WATER WALL WARMS ROOM AND GREENHOUSE AT NIGHT

Figure 9. Attached Greenhouse.

Before recommending an attached greenhouse or sunspace, the energy auditor should consider the following:

- Building configuration: The building should extend east to west and allow the construction of the greenhouse on the southern exposure, adjacent to the spaces to be heated.
- Collector glazing: To achieve the same amount of heat gain, the glass area of the greenhouse must be approximately 1.5 times as large as the surface area of a thermal storage wall. This area can be reduced if an active heat storage system is incorporated into the greenhouse system.
- Construction and thermal storage material: No restraints are placed on the materials used for any parts of the building, except the greenhouse and the thermal storage wall. The greenhouse should be constructed of double glass or transparent plastic. The thermal storage wall should be designed according to the same criteria as those used to design the thermal storage wall systems discussed previously.
- Thermal control: Methods for controlling interior temperatures are the same as those discussed on thermal storage walls. The range of temperatures is controlled by properly sizing and positioning the collector area and thermal mass.
- Thermal efficiency: The greenhouse both heats itself and supplies heat to the living space. Since all admitted sunlight is used for heating, the winter efficiency of the greenhouse is on the order of 60% to 70%. Approximately 10% to 30% of the energy incident on the collector surfaces is actually transferred to the living space.
- Potential for retrofitting: Greenhouses and sunspaces are easily added to the southern walls of existing buildings with clear southern exposures.

In addition to providing heat, the greenhouse can also produce food. In some cases where the utility and food bill savings have both been taken into account, greenhouses have produced payback periods as short as 1 to 3 years.

ROOF PONDS

The principle of heat flow in the roof pond system is the same as that in the indirect gain system, which uses a water thermal storage wall. In the roof pond system, however, the water for thermal storage is located in thin plastic bags supported on the roof by metal decks. These decks also serve as the ceiling for the room below and as extensive, efficient radiating surfaces.

In operation, the ponds are exposed to the sun during winter days to absorb heat, and then covered with insulating panels at night to preserve as much of the heat as possible (see Figure 10). The heat is then radiated directly to the room beneath the roof pond. In summer, in some climates, the procedure can be reversed – the ponds being covered during the daytime to prevent heat gain, and uncovered at night to dissipate by natural convection and radiation on cool summer nights.

Before recommending a roof pond system, the energy auditor should consider the following:

- Building configuration: Since the heat from a roof pond is radiated directly to the room below, the applicability of roof pond systems is limited to single-story structures or to the upper floors of multi-story structures. Because the radiation is absorbed in a horizontal plane rather than a vertical one, there are no restrictions on building shape or orientation.
- Collector glazing: Ponds should be unobstructed by shadow from 10 a.m. to 2 p.m. in winter and have maximum night exposure in summer.
- Construction and thermal storage material: Since ponds are typically 6-12 inches deep, the roof must support a dead weight of 30-65 lb/sq ft. This support is typically supplied by a metal deck, which acts as pond support, ceiling, and radiating surface. No restrictions are placed on construction materials for the rest of the structure.

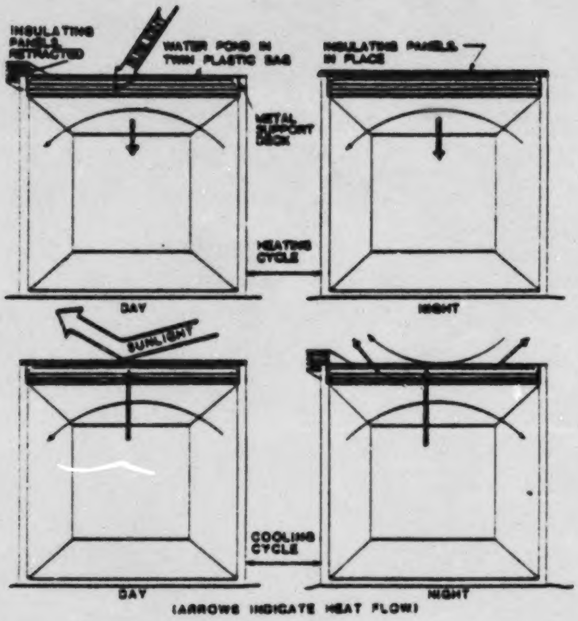

INSULATING PANELS RETRACTED
WATER POND IN TWIN PLASTIC BAG
INSULATING PANELS IN PLACE
METAL SUPPORT DECK
HEATING CYCLE
DAY
NIGHT
SUNLIGHT
COOLING CYCLE
DAY
NIGHT
(ARROWS INDICATE HEAT FLOW)

Figure 10. Roof Pond.

- Thermal control: The large radiative surfaces of roof pond systems provide high comfort levels and stable temperatures. In masonry buildings, temperature fluctuations are typically within the range of 5°F to 8°F; in buildings constructed of lightweight materials, temperature fluctuations are on the order of 9°F to 14°F.
- Thermal efficiency: In a double-glazed roof pond system, thermal efficiency is in the range of 30% to 45%.
- Potential for retrofitting: It is extremely difficult to install a roof pond system if provision for it is not made in the initial construction.

Roof ponds are an inexpensive, effective passive heating system in latitudes below 36°NL. In dry climates where there are clear night skies, roof ponds can also be effective passive cooling systems. With proper architectural design, the usefulness of roof ponds in both heating and cooling can be extended into other locations.

ISOLATED GAIN SYSTEMS

In isolated gain systems, the heat collection and storage systems are isolated from the living area. This arrangement allows the system to function independently from the living space and supply heat only when necessary.

Isolated gain systems function on the principle of the natural convective loop, as shown in Figure 11. As the storage medium is heated in the collector, it rises to the heat storage bin and is replaced by cooler water or air according to the particular system.

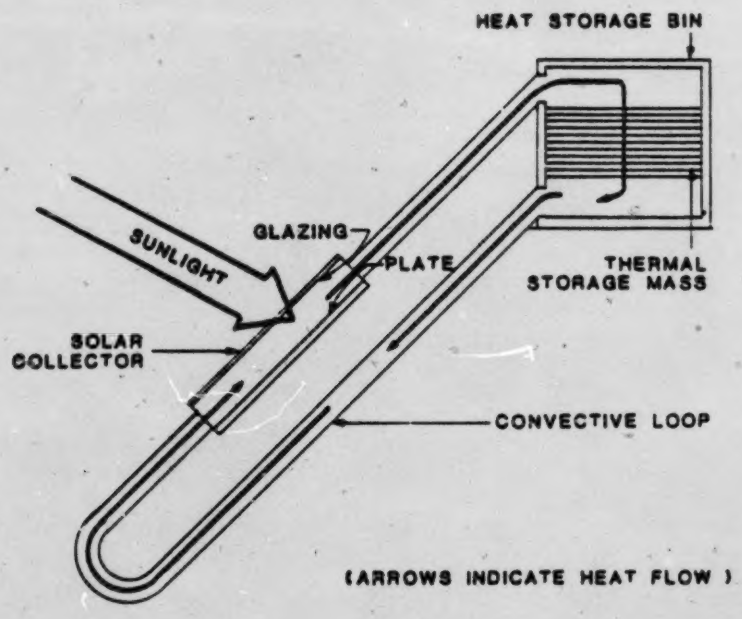

HEAT STORAGE BIN
SUNLIGHT
GLAZING
PLATE
THERMAL STORAGE MASS
SOLAR COLLECTOR
CONVECTIVE LOOP
(ARROWS INDICATE HEAT FLOW)

Figure 11. Isolated Gain: Convective Loop.

Installation of isolated gain systems are under way, and information an energy auditor would need to recommend an isolated gain system has been compiled and analyzed.

EXERCISES

1. Although many alternative energy sources are being explored, only a few are of great significance for the energy auditor. Why?
2. Explain the concept of a "hybrid" solar water heating system.
3. Explain the importance of the reflective roof surface.
4. Discuss thermocirculation and its importance in passive solar space heating systems.
5. Explain how roof ponds can provide both space heating and space cooling.
6. Discuss heat flow in an indirect gain space heating system. (Discussion should include both masonry and water thermal storage systems. Conduction, convection, and radiation should also be considered.)
7. Explain why indirect gain and greenhouse passive solar heating systems are more likely to be applicable to existing structures than direct gain systems.

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TEST

Enter True or False in the blank after each statement.

1. A hybrid solar hot water system combines the elements of a passive system with those of a conventional fossil fuel or electric system. ________
2. With an air system, transport of heat over long distances is more costly than it would be with a liquid system. ________
3. Photovoltaic cells can significantly reduce the cost per kWh of electricity consumed in a typical commercial facility. ________
4. A direct gain system is so named because sunlight strikes the thermal storage medium directly, rather than passing through the windows and room first. ________
5. Generally, the most important consideration in retrofitting an existing structure with any type of passive solar heating system is the construction material. ________
6. Isolated gain systems are one of the newest passive solar energy systems. ________
7. With water-type solar collectors, selective surfaces on absorber plates become less beneficial as temperature requirements increase. ________
8. Currently, the greatest problem with active solar space cooling systems in that absorption units cannot operate at temperatures in the range of 160°F to 180°F. ________
9. Because the effective range of temperature radiation is 15-20 feet, active solar space heating systems are limited to residential and small commercial applications. ________

10. One great advantage of passive solar space heating systems is that their many mechanical parts are standard hardware/construction items. _________

Complete the following sentences.

11. _________ surfaces are more efficient than flat black surfaces in solar collectors.

12. For relatively small buildings, when space heating is the only load on the active solar system, _________ collectors may be most suitable.

13. In a water-filled thermal storage wall, the surfaces stay relatively cool due to the heat transfer process of _________.

14. In an isolated gain system, the heat collection and storage medium circulates through a _________.

15. _________ is the solar collector tubing material most resistant to corrosion and pitting.

ENERGY AUDIT
WORKBOOK

MODULE EA-11

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT
601 LAKE AIR DRIVE
WACO, TEXAS 76710

AUG. 1981

CE 030 789

PREFACE

The Energy Audit Workbook provides a step-by-step approach to gathering the necessary information for performing an energy audit. Modules EA-01 through EA-10 should be used as reference. While different auditing assignments may require many different forms and checklists, the ones presented herein are basic and standard. They are:

- Energy Inventory
- Energy Audit Checklist
- Condition Summary
- Evaluation of Potential for Energy Conservation Measures
- Evaluation of Potential for Solar and Renewable Resource Measures
- Potential Energy Saving Calculations

Familiarity with these forms and checklists should enable the energy auditor to meet any particular reporting requirements.

Students should read through the material in the Workbook and work as many calculations as possible (supplying aribtrary figures when necessary).

TABLE OF CONTENTS

Page

Energy Inventory 1
    General Administrative Information 3
    Occupancy Patterns/Operating Conditions/
      Climate Information/Activity Groups 4
    Physical Characteristics 5
    Annual Energy Consumption Summary 6
    Energy Systems:
        Lighting 11
        HVAC 12
        Heating and Cooling Sources 13
        Water Usage 14
        Special Services 15
    Solar and Renewable Resource Potential 17
    General Remarks 18

Energy Audit Checklist 19
    Administration 20
    Lighting 32
    Building Envelope 40
    Ventilation 48
    Heating 56
    Cooling 74
    Water 88

Condition Summary 93

Evaluation of Potential for Energy Conservation Measures . . . 97

Evaluation of Potential for Solar and Renewable Resource
  Measures 101

Potential Energy Saving Calculations 105
    Preliminary Calculations:
        Energy Consumption for Heating 107
        Energy Consumption for Cooling 109
    O&M/Energy Measures:
        Administration 111
        Lighting 121
        Building Envelope 132
        Ventilation 139
        Heating 143
        Cooling 152
        Water 159

Calculation Reference Material
    General Reference. Energy and Power Conversions 163
    Figure 1. Heating and Cooling Zones 164

Page

Table 1. U Values for Typical Wall and Roof Construction (Walls) 165
Table 2. U Values for Glass 166
Table 3. U Values for Typical Wall and Roof Construction (Roofs) 167
Table 4. Data on Normal Heating Season in U.S. Cities 168
Table 5. Air Conditioning Data 171
Table 6. Approximate Power Inputs 171
Table 7. Estimated Equivalent Full-Load Operating Hours for Normal Cooling Season 172
Table 8. Data on Normal Cooling Season for Selected U.S. Cities 173
Table 9. Total Solar Insolation on a Vertical Surface 174
Table 10. Mean Percentage of Possible Sunshine for Selected Locations 175
Table 11. Shading Coefficients 179
Table 12. Monthly and Annual Heating Degree Days 180
Table 13. Monthly and Annual Cooling Degree Days 187
Table 14. Heat Loss for Various Pipe Sizes, Insulation Thicknesses, and Water Temperatures 193
Table 15. Heat Loss for Various Pipe Sizes, Insulation Thicknesses, and Water Temperatures 194
Table 16. Heat Gain for Various Pipe Sizes and Insulation Thicknesses 195
Table 17. Average Hot Water Consumption for Various Institutions 196
Table 18. Solar Insolation for Collectors Tilted 10° Plus North Latitude from Horizontal . . . 196

ENERGY INVENTORY

ENERGY INVENTORY

The following Energy Inventory Form, or its equivalent, should be completed by management and/or operational staff before the audit is initiated. This information is essential to an understanding of building energy demand, using the audit checklist, preparing a report of the energy audit, and developing a realistic energy management program. (Information elements marked with an asterisk (*) are not specifically required by federal rule-making but can be useful for energy management programs in individual institutions.)

The Energy Inventory organizes important data concerning the building or facility according to the following categories:

A. General Administrative Information
B. Occupancy Patterns/Operating Conditions/Climate Information/ Activity Groups
C. Physical Characteristics
D. Annual Energy Consumption Summary
E. Energy Systems:
    a. Lighting
    b. HVAC
    c. Heating and Cooling Sources
    d. Water Usage
    e. Special Services
F. Solar and Renewable Resource Potential
G. General Remarks

It is suggested that the different categories of the Energy Inventory Form be completed by the following qualified personnel:

Category	Performed By
General Administrative Information; Occupancy Patterns/Operating Conditions/Climate Information/Activity Groups; Annual Energy Consumption Summary	Building administrative personnel
Physical Characteristics and Energy Systems: Lighting, Water Usage	Maintenance personnel
Energy Systems: Ventilation, and Heating and Cooling	Building engineer (In the absence of building engineer, maintenance personnel should complete these sections.)
Energy Systems: Special Services	Special services personnel

The implementation of energy conservation maintenance and operating procedures is a condition for eligibility for receiving federal assistance under the Technical Assistance Program. Should technical questions arise concerning mechanical equipment in operation in the building, the engineer or appropriate service company should be consulted.

ENERGY INVENTORY FORM

A. GENERAL ADMINISTRATIVE INFORMATION

1-2. Indicate if single building or complex; enter the name; check the appropriate ownership, type and category. If other applies, enter a one- or two-word description. (For example, a hospital which is neither a general hospital nor a TB hospital would check "other" and add "obstetrics and gynecology" or "eye, ear, nose, and throat," "orthopedic," "chronic disease," or other appropriate brief description.

3-4. Provide building address (do not use P.O. Box number – enter street address) and phone number. Note year constructed and date of last major addition or modification.

5-6. Record names and telephone numbers of building manager and building operator; record names of mechanical and electrical engineers. Record names and telephone numbers of persons responsible for the building.

7. Has an energy management coordinator been designated?

8. Indicate whether major changes are anticipated in the facility proper or in its function for the next 15 years; e.g., new construction, rehabilitation, or demolition.

9. Indicate whether any other energy audit work has been completed or is currently under way.

10. Describe any conservation measures that have been implemented or are being considered and expected cost and energy savings expressed as an annual percentage reduction in the type of fuel affected. Attach additional page if necessary.

11. Describe any previous architectural/engineering studies.

12. Provide the names of the original architects and engineers of the building.

---

1. Name of Building or Complex: ____
   Owner: ____
   Public ____ Private ____
   Non-Profit ____ Indian Tribe ____

2. Building Type and Category:

☐ School
- ___ Elementary
- ___ Secondary
- ___ Junior College
- ___ College or Univ.
- ___ Vocational
- ___ Other, Specify ____

☐ Hospital
- ___ General
- ___ Tuberculosis
- ___ Psychiatric
- ___ Other, Specify ____

☐ Local Gov't.
- ___ Office
- ___ Storage
- ___ Library
- ___ Services
- ___ Police Station
- ___ Fire Station
- ___ Other, Specify ____

☐ Public Care
- ___ Nursing Home
- ___ Long-term Care
- ___ Rehab. Center
- ___ Orphanage
- ___ Public Health Ctr.
- ___ Residential Child Care
- ___ Other, Specify ____

3. Building Address: ____ City ____
   State ____ Zip ____ Telephone Number ____

4. Year Constructed: ____ Year of Last Major Addition or Modification: ____

5. Building Manager: ____ Telephone Number: ____
   Building Operator: ____ Telephone Number: ____
   Person Responsible for Building: ____
   Telephone Number: ____

*6. Mechanical Engineer: ____ Electrical Engineer: ____

7. Energy Management Coordinator Designated: Yes ☐ No ☐

8. Anticipated Building Modifications: ____

9. Previous Energy Audit Work Completed: Yes ☐ No ☐ Specify: ____

10. Conservation Measures (Retrofit) Already Implemented or Under Consideration:
    Yes ☐ No ☐ Specify Project, Cost and Expected Energy Savings: ____

11. Previous Architectural/Engineering Studies: Yes ☐ No ☐ Specify: ____

12. Original Architects: ____
    Original Engineers: ____

B. OCCUPANCY PATTERNS/OPERATING CONDITIONS/CLIMATE INFORMATION/ACTIVITY GROUPS

1. Complete occupancy schedule. If the institution operates on a seasonal schedule, or has other periods of at least a week's duration when the building is only partially occupied, the number of weeks partial use by calendar quarter should be entered, along with the approximate percentage of total gross square feet in use during such periods.
2. Provide summer/winter operating conditions: average indoor temperature, normal indoor relative humidity, outside design temperature, average seasonal relative humidity.
3. Note U.S. heating and cooling zone in which building is located and climate information unique to the location. Refer to heating and cooling degree data.
4. List the kinds of activities housed within the building.

1.

Day(s)	Time Period	Average Occupancy or	% gsf Occupied	Number of Hours	Weeks/Year
Mon-Fri	day				
	evening				
	night				
Saturday	day				
	evening				
	night				
Sunday	day				
	evening				
	night				

Quarterly Partial Usage:

Quarter	Weeks	% gsf
1st		
2nd		
3rd		
4th		

*2. Operating Conditions:

	Summer	Winter
Average Indoor Temperature	____ °F	____ °F
Indoor Relative Humidity	____ %	____ %
Outside Design Temperature	____ °F	____ °F
Outside Relative Humidity	____ %	____ %

3. Building Location:
U.S. Heating Zone # ____________________ U.S. Cooling Zone # ____________________
Annual Heating Degree Days ____________________ Annual Cooling Degree Days ____________________
(Base 65°F) (Base 65°F)

*4. List facility activities (e.g., radiology, school administration, mayor's office and staff, etc.) and approximate area and time devoted to each.
a. ____________________ area ______________ sq. ft. time worked ____________ hrs/day
b. ____________________ area ______________ sq. ft. time worked ____________ hrs/day
c. ____________________ area ______________ sq. ft. time worked ____________ hrs/day
d. ____________________ area ______________ sq. ft. time worked ____________ hrs/day
e. ____________________ area ______________ sq. ft. time worked ____________ hrs/day

(If more space is needed, attach a separate sheet.)

C. PHYSICAL CHARACTERISTICS

1. To calculate gross square feet (gsf), multiply the outside dimensions or measure from the centerline of common walls and multiply by the number of floors. If the building has wings, or the number of floors varies in one part from another, divide the building into sections, calculate the area of each section, and total. (Deduct from the total area any parking garages or other areas that are neither heated nor cooled.) To obtain building volume, multiply average ceiling height times gross floor area.
2. Total the exterior glass area (excluding skylights), noting whether glass is single or double pane.
3. Total the exterior wall surface area (excluding glassed area), noting predominant wall material. Indicate approximate overall thermal transmittance (U_o) for wall structure by multiplying area times U value.
4. Compute surface area of roof (excluding total skylight area). Note general condition. Indicate approximate overall thermal transmittance (U_o) for roof structure by multiplying area times U value.

5-6. Note type and thickness of insulation material in roof, walls, and floors. Note if there is none.

7. Sketch position of facility on site with North arrow.
8. Briefly describe general building conditions.

---

1. Gross Floor Area: __________ gsf x Ceiling Height __________ ft = Volume __________ cu. ft.

*2. Total Exterior Glass Area: __________ sq. ft.
Single Panes __________ sq. ft.
Double Panes __________ sq. ft.

	North Side	South Side	East Side	West Side
Total Area	________ sq. ft.	________ sq. ft.	________ sq. ft.	________ sq. ft.
Single Pane	________ sq. ft.	________ sq. ft.	________ sq. ft.	________ sq. ft.
Double Pane	________ sq. ft.	________ sq. ft.	________ sq. ft.	________ sq. ft.

*3. Total Exterior Wall
Area: __________ sq. ft.
U_o: __________ Btu/hr/°F
Material: Masonry _____ Wood _____ Other _____
Concrete _____ Stucco _____

*4. Total Roof
Area: __________ sq. ft.
U_o: __________ Btu/hr/°F
Condition: Good _____ Fair _____ Poor _____

*5. Insulation Type: Roof ____________ Wall ____________ Floor ____________

*6. Insulation Thickness: Roof ____________ Wall ____________ Floor ____________

7. What is orientation of building on site? (Draw sketch with North arrow.)

8. Description of general building conditions:
____
____
____
____
____
____
____

D. ANNUAL ENERGY CONSUMPTION SUMMARY

1-9. Complete fuel use summary for base year (or last 12 months if no base year has been established), using utility records and Energy Data Forms provided. (If no past records have been kept, call the utility.) Multiply by the conversion factors (as required by the Federal Register, Section 450.42(11), April 2, 1979) and enter the results in Column D as annual Btu consumption. Transfer annual cost for each fuel from the appropriate Energy Data Form to Column E. Compute consumption in Btus per gross square foot per year by dividing the total of the entries in Column D by gsf. Compute energy dollars per gross square foot per year by dividing the total of the entries in Column E by gsf. (Obtain gross floor area from previous page and energy costs from Energy Data Forms.)

10. Based on past year's utility bills, complete peak electrical demand data. For buildings or complexes over 200,000 gsf, or if the electric rate contains a demand charge, determine if demand is recorded. Note times at which typical peaks occur during daily operation. Also note whether demand fluctuates on a seasonal basis indicating month in which the highest demand occurs.

11. If data is available, indicate the fuel used by each of the major energy-using systems listed and the annual consumption of each. For "special," indicate special purpose facilities (e.g., food service, laundry) which use significant amounts of energy, fuel type used, and annual usage.

	A	B	C	D	E	F	G
	Fuel	Previous 12 Month Totals	Conversion Factor =	Btus Consumed	Annual Cost	Btu/gsf/yr	$/gsf/yr
1.	Electricity	kWh x	11,600 =				
2.	Natural Gas	CCF x	103,000 =				
3.	#2 Oil[1]	gallons x	138,690 =				
4.	#6 Oil[2]	gallons x	149,690 =				
5.	Steam	pounds x	1,390 =				
6.	Coal	tons x	24,500,000 =				
7.	Propane	gallons x	95,475 =				
8.	Other, Specify[3]	x	=				
9.	TOTALS	▨	▨				

[1] #2 oil should include other distillate fuel oils.
[2] #6 oil should include other residual fuel oils.
[3] Use a standard engineering reference manual or factors provided by the State for other fuels.

10. Peak Electrical Demand:

Annual: ____________________ kW
Month: ____________________

11. Fuel Use by Major Energy-Using Systems:

System	Fuel Type	Annual Use
Heating		
Cooling		
Hot Water		
Lighting		
Special, Specify		

ENERGY DATA FORM

	A		B		C		D		E		F		G	
Month	Reading Date		kWh Used		Measured Demand kW		$ Cost		(FCA) Fuel Cost Adjustment ($)		Total Cost (D + E = F)		$/kWh (F ÷ B = G)	
	From	To	Current	Base	Current	Base	Current	Base	Current	Base	Current	Base	Current	Base
Jan														
Feb														
Mar														
Apr														
May														
Jun														
Jul														
Aug														
Sep														
Oct														
Nov														
Dec														
Column B Totals														

On-Site Conversion Factor	x 3,413	x 3,413
Total Btus		
Column B Totals		
Point of Generation Btu Conversion Factor	x 11,600	x 11,600
Total Btus		

ELECTRICITY ______________________ kWh/yr

Electricity Rate No. ____________

Building ______________________________

ENERGY DATA FORM

	A		B		C		D		E		F		G	
Month	Reading Date		Gas Used CCF		Gas Cost		Gas Cost Adjustment		Total Cost (C + D = E)		$/CCF (E ÷ B = F)		Heating Degree Days	
	From	To	Current	Base	Current	Base	Current	Base	Current	Base	Current	Base	Current	Base
Jan														
Feb														
Mar														
Apr														
May														
Jun														
Jul														
Aug														
Sep														
Oct														
Nov														
Dec														

TOTAL		
Btu Conversion Factor	x 103,000	x 103,000
Total Btus		

NATURAL GAS ______________________________ CCF/yr

Natural Gas Rate No. _______________

Building _____________________________________

ENERGY DATA FORM

	A		B		C		D		E		F	
Month	Reading Date		Fuel Used (Gallons)		$ Cost		$/Gallon (C ÷ B = D)		Heating Degree Days		Fuel Used Per Degree Day (B ÷ E = F)	
	From	To	Current	Base	Current	Base	Current	Base	Current	Base	Current	Base
Jan												
Feb												
Mar												
Apr												
May												
Jun												
Jul												
Aug												
Sep												
Oct												
Nov												
Dec												
TOTAL												

Conversion Factor:		
#2 Oil	x 138,690	x 138,690
#6 Oil	x 149,690	x 149,690
Propane	x 95,475	x 95,475
Other	x	x
Total Btus		

OIL ☐ #2 Oil ☐ #6 Oil ______________________ gal/yr

PROPANE ________________ gal/yr Other ______________ gal/yr

Percentage Total Consumption ______________________ %

Current Year ________________ Base Year ______________

ENERGY DATA FORM

	A		B		C		D		E		F	
Month	Reading Date		Steam Used (1000's of lbs)		$ Cost		$'s Per 1000 lbs (C ÷ B = D)		Heating Degree Days		Steam Used Per Degree Day (B ÷ E = F)	
	From	To	Current	Base	Current	Base	Current	Base	Current	Base	Current	Base
Jan												
Feb												
Mar												
Apr												
May												
Jun												
Jul												
Aug												
Sep												
Oct												
Nov												
Dec												
Column B Totals												
On-Site Btu Conversion Factor			x 1,000	x 1,000								
Total Btus												
Column B Totals												
Point of Generation Btu Conversion Factor			x 1,390	x 1,390								
Total Btus												

STEAM ______________________________ lbs/yr

Percentage Total Consumption ________________ %

Current Year ______________________________

Base Year ______________________________

E. ENERGY SYSTEMS

a. Lighting

1-2. For each lighting type, fluorescent and incandescent, note the percentage of gross square feet of the building illuminated. Include an estimate of average usage in hours per week and hours per year.

3. Determine the total wattage presently used to illuminate the building's interior and divide by the gross floor area to compute an average lighting level in watts per square foot.

4. Note total interior and exterior loads in kilowatts by adding the wattages of all lamps (separately for each) and dividing by 1000.

5. Note any unusual lighting applications.

---

1. Fluorescent:
Percentage of gsf: __________ % Usage: __________ hr/wk __________ hr/yr

2. Incandescent:
Percentage of gsf: __________ % Usage: __________ hr/wk __________ hr/yr

*3. Average Interior Lighting Level: ______________ watts/ft^2

*4. Total Interior Lighting Load: ____________ kW
Total Exterior Lignting Load: ____________ kW

*5. Unusual Lighting Applications:
____
____
____
____
____

E. ENERGY SYSTEMS

b. HVAC

1-10. Check the type and capacity of HVAC systems found in the building. If knowledge of the system is not available, obtain the information from the mechanical engineer, blueprints, specifications, or nameplates. Total the cubic feet per minute (cfm) of air that the air systems supply to the building. Note what percentage of outside air is used. Note the heating and cooling capacities and fan horsepower. If a building complex is being audited, provide this information for each building. Attach an additional sheet if needed.

11-13. Economizer Cycle: An economizer cycle is the air-handling equipment utilizing outdoor air during the winter season to cool the interior of the building. Two types of economizer cycles are enthalpy control and dry bulb changeover temperatures.

	System Type	Total cfm	Minimum % Outside Air	Capacity Btu/hr	Fan Horsepower
1.	Terminal Reheat				
2.	Multi-Zone				
3.	Dual Duct				
4.	Variable Air Volume				
5.	Induction				
6.	Fan Coil	▨			
7.	Heat Pump				
8.	Air Exhaust		▨	▨	
9.	Radiation	▨	▨		▨
10.	Other				

*11. Economizer Cycle: Yes ______ No ______

*12. If yes, indicate changeover temperature: ______ °F (dry bulb)

*13. If yes, indicate if enthalpy control: Yes ______ No ______

E. ENERGY SYSTEMS

c. Heating and Cooling Sources

Heating

1-3. Note the principal fuel used by the heating system. Obtain the rated output (energy output of system in Btus or kWhs) and the rated input (amount of energy required to obtain the specified rated output) from the equipment specifications.

4-6. Larger buildings tend to have boilers or purchase hot water or steam. Smaller buildings tend to have unitary direct-fired equipment. Determine the system type. Estimate the number of hours per day and weeks per year that the heating plant operates.

Cooling

1-3. Note the principal fuel used by the cooling system. Obtain the rated input consumption figure required to generate full capacity cooling from specifications.

4-6. Examine the equipment to determine system type. Estimate the number of hours per day and weeks per year that the system operates.

	Heating System	Cooling System
1.	______________ Fuel Type	______________ Fuel Type
*2.	______________ Rated Input Consumption	______________ Rated Input Consumption
*3.	______________ Rated Output Capacity (Btu/hr)	______________ Rated Output Capacity (tons)
4.	System Types: (Check ✓)	System Types: (Check ✓)
	___ Boilers	___ Absorption
	___ Purchased water or steam	___ Electric Drive
	___ Unitary Direct-Fired	___ Steam Turbine Drive
	___ Furnaces	___ Water-Cooled Packaged Unit
	___ Package Equipment	___ Air-Cooled Packaged Unit
*5.	Operation Profile:	Operation Profile:
	___ hrs/weekday	___ hrs/weekday
	___ hrs/Saturday	___ hrs/Saturday
	___ hrs/Sunday	___ hrs/Sunday
*6.	If not 52 wks/yr:	If not 52 wks/yr:
	___ wks/yr	___ wks/yr
	___ from (month)	___ from (month)
	___ through (month)	___ through (month)

E. ENERGY SYSTEMS

d. Water Usage

1-2. Arbitrarily select a base year. Examine the water bill and note the reading dates. Note water used for each period in gallons. Note water costs for each quantity of water usage and compute what this means in terms of $/gallon. Indicate heating source.

3-4. Estimate the number of gallons of hot water used per day. The difference between the delivery temperature of hot water and the average ground temperature of city water is the temperature rise. Record it now for later use.

---

*1.

Reading Dates		Water Used (Gallons)	Cost	$/Gallon
From	To	Base Year	Base Year	Base Year
Totals				

2. Domestic Water Heated By: Electricity _______ Natural Gas _______ Other _______

*3. Daily Usage:
Gallons/Day _______________

*4. Delivery Temperature ___________ °F
Average Temperature of City Water ___________ °F
Temperature Rise ________ °F (delivery temperature - city water temperature)

E. **ENERGY SYSTEMS**

e. Special Services

1. Are laundry services provided? If so, note the number of washer/dryers, each washer/dryer's capacity, and the total weekly load.
2. Are food services provided? Complete the "Food Preparation and Storage Area Equipment" chart on the following page, if applicable.
3. Are other special services provided?

---

1. Laundry Yes ☐ No ☐

Enter Fuel Type: N.G. = Natural Gas, E = Electricity

Washing Data			Drying Data			
Number of Washers	Washer Capacity	Total Weekly Loads	Number of Dryers	Dryer Capacity	Total Weekly Loads	Fuel Type
	lbs			lbs		
	lbs			lbs		
	lbs			lbs		
	lbs			lbs		
	lbs			lbs		
	lbs			lbs		

2. Food Yes ☐ No ☐

On the following chart, check the kitchen equipment used in food preparation and storage. Where possible, record information from equipment nameplates. Use the "comments" column to note general condition and equipment.

3. Other Yes ☐ No ☐

Describe briefly: ______________________________

____

____

____

____

FOOD PREPARATION AND STORAGE AREA EQUIPMENT

	A	B	C	D	E	F
Description	Number of Units	Nameplate Information (Kilowatts, Btu/hr)	Hours Operated Daily	Days/Yr In Use	Annual Consumption (kWh or Btu) AxBxCxD	Additional Comments
Ranges						
Ovens						
Steam Tables						
Frying Tables						
Freezers						
Refrigerators						
Infra-Red Warmers						
Dishwashers						
Microwaves						
Hoods With Exhaust Fans						
Mixers						
Other						

F. SOLAR AND RENEWABLE RESOURCE POTENTIAL

1. Check characteristics of adjacent property.
2. Indicate nature of location.
3. Note building characteristics, indicating shape as square, rectangular, E-shaped, H-shaped, L-shaped, or attach a rough sketch of the configuration.
4. Note roof design. For the orientation of a pitched roof, indicate the compass direction of a line perpendicular to the ridge line in the direction of the downslope. Note presence of roof obstructions such as chimneys, space conditioning equipment, water towers, mechanical rooms, and stairwells. Identify the principal structural material of the roof; e.g., steel, concrete, or wood structural components. Also, identify the type of roofing such as shingle, slate, or built-up.
5. Indicate nature of southern-facing wall.
6. Check type and location of heating equipment.
7. Using information from the National Weather Service, the State's energy office, or from charts provided, enter monthly average insolation and wind speeds.
8. Note any special conditions or characteristics related to potential for solar or other renewable resource application.

---

1. Adjacent open land (not heavily shaded):

☐ Field ☐ Yard ☐ Parking Lot Other, Specify ______________________

2. Location:

☐ Urban ☐ Suburban ☐ Rural

3. Building characteristics:

☐ Roof Unshaded ☐ Southern Wall Unshaded

Number of Stories ________ General Shape ______________

4. Roof:

☐ Flat ☐ Pitched, Orientation ______________ Primary Structural Material __________ Type of Roofing ________

Roof obstructions: ______________________________________

5. Composition of Southern Facing Wall: ______________________________

____

Southern-Facing Wall Glass Area:

☐ Less than 25% ☐ 25% to 75% ☐ Over 75%

6. Type and location of space heating equipment:

☐ Single Unit ☐ Multiple Units

☐ Outside, Location ______________________________

☐ Inside, Location ______________________________

Type and location of water heating equipment:

☐ Single Unit ☐ Multiple Units

☐ Outside, Location ______________________________

☐ Inside, Location ______________________________

7. Average Insolation:

Average Insolation (Btu/ft^2/yr)

Jan ___ April ___ July ___ Oct ___
Feb ___ May ___ Aug ___ Nov ___
Mar ___ June ___ Sept ___ Dec ___

Average Wind Speed:

Average Wind Speed (miles/hr)

Jan ___ April ___ July ___ Oct ___
Feb ___ May ___ Aug ___ Nov ___
Mar ___ June ___ Sept ___ Dec ___

8. Remarks

____

____

____

____

____

G. GENERAL REMARKS

Provide any additional information considered to be pertinent to the preliminary energy audits or any explanations necessary for understanding entries elsewhere on the forms.

Remarks: ______________________________

ENERGY AUDIT CHECKLIST

ENERGY AUDIT CHECKLIST

After a basic understanding of the facility has been gained through completion of the Energy Inventory, the energy auditor is ready to schedule a walking tour of the building. Outside areas as well as the main buildings are to be included in the tour, which should be conducted during normal operating hours.

The checklists that follow are organized according to building systems. Trouble spots are indicated by appropriate symptoms or conditions, each capable of being observed by individuals with nontechnical backgrounds in energy management. (No elaborate equipment is required; however, it is recommended that, if available, a standard dry-bulb thermometer, a light meter, and the building plans be used to facilitate data collection.)

Corresponding to each condition are appropriate operational and maintenance (O&M) and conservation measures (retrofit options) that can rectify the problem. The O&M options should be implemented, where possible, before considering the energy conservation measures. A record of progress should be kept by indicating the dates of implementation of O&M options, initials of "implementors," and whether applicable. Energy measures should be checked if they are to be considered or if they do not apply.

Auditors and/or energy management teams should give first priority to the operational and maintenance options — usually the most rapid means of reducing energy consumption. Operational and maintenance options include the rest or readjustment of existing systems to achieve increased efficiency and generally involve "no-cost" or "low-cost" procedures. Only when all possible operational and maintenance options have been employed should the more capital intensive energy measures (retrofit and redesign options) be considered.

ENERGY AUDIT CHECKLIST

ADMINISTRATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

A-1 Thermostats on heating/cooling units are vulnerable to occupant adjustment.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Reset thermostats to correct settings.
- Install or replace locking screws to prevent tampering.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Install tamper-proof locking covers on thermostats.
- Install preset solid state electric thermostats if existing controls are electric.
- Relocate thermostats in return air ducts where they will be inaccessible to occupants.

ENERGY AUDIT CHECKLIST

ADMINISTRATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

A-2 Thermostat settings have not been adjusted for change in seasons.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Adjust thermostats to 68°F in heating season and to 78°F during cooling season.
- Change the location of thermostats from areas subject to extreme temperature fluctuations, such as next to windows or over a heating or cooling unit.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Replace existing thermostat with a thermostat that has a separate setting for cooling and a separate setting for heating, or use one thermostat to control heating and one thermostat to control cooling.

ENERGY AUDIT CHECKLIST

ADMINISTRATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

A-3 Unoccupied or little used areas are heated or cooled unnecessarily.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Reduce winter thermostat settings to 55°F in unoccupied areas.
- Where possible, turn off heating systems if nothing in space can freeze.
- Use spot heaters/coolers in large spaces with low occupancy.
- Turn off cooling systems in unoccupied areas, if possible.
- Disconnect electrical devices, close drapes, and shut off air systems if nothing in space can freeze.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- Install system controls to reduce heating/cooling of unoccupied spaces.

ENERGY AUDIT CHECKLIST

ADMINISTRATION

CONDITION

☐ EXISTS
☐ DOES NOT EXIST

A-4 Off-hour activities are scheduled.

SUGGESTED O&M OPTIONS

DATE COMPLETED
INITIALS
N.A.

- Reschedule off-hour activities to accommodate partial shutdown of building systems.
- Reschedule custodial and cleaning activities during working hours whenever possible.
- Reexamine original assumptions regarding occupancy patterns and building usage. Modify patterns for increased energy efficiency.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED
N.A.

- Install an automated energy management system that will control all spaces in accordance with usage.

ENERGY AUDIT CHECKLIST

ADMINISTRATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

A-5 Building temperatures are not adjusted for unoccupied periods.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Reduce thermostat settings by a minimum of 10°F at nights, for weekends, and holidays during heating season.
- Shut down all air-conditioning units at night, on weekends, and holidays.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Install automatic controls such as time clocks or automated management systems.

ENERGY AUDIT CHECKLIST

ADMINISTRATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

A-6 Heating/cooling equipment is operating in lobbies, corridors, vestibules and/or other public areas.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Close supply ducts and radiators and/or lower heating set points in the above areas if there is no possibility of freeze-up. Disconnect electrical heating units (or switch off at breaker box).
- Close air-conditioning supply ducts serving the above areas.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Properly adjust and balance air/water systems and controls.

ENERGY AUDIT CHECKLIST

ADMINISTRATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

A-7 Heating/cooling equipment is started before occupants arrive and/or is operating during last hour of occupancy.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Experiment with start-up times and duration of operation to determine satisfactory comfort levels for occupants. Reduce or turn off heating and cooling during the last hour of occupancy, allowing the building to "coast."

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Install a time clock or an automated energy management system that will reduce heating and/or turn off air conditioner.

ENERGY AUDIT CHECKLIST

ADMINISTRATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

A-8 Use of equipment associated with laundry and custodial services coincides with heavy electrical demand periods.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Require that major electrical equipment be used in accordance with guidelines that avoid peak electrical demand periods.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Install a demand control system to automatically monitor power demand and to shut off assigned secondary loads to lower demand peaks to pre-established level.

ENERGY AUDIT CHECKLIST

ADMINISTRATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

A-9 Blinds and curtains are not used to help insulate the building.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Instruct personnel to close interior shading devices to reduce night heat loss in winter and to reduce solar heat gain during the summer.
- Repair or replace damaged or missing shading devices.
- Place reminders where appropriate.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Add reflective or heat absorbing films to reduce solar heat gain in summer. (Caution: Natural lighting and solar heat gain in winter will be reduced. Also, unless protected by an additional layer of glass, these films are subject to damage.)
- Install outdoor shading devices.

ENERGY AUDIT CHECKLIST

ADMINISTRATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

A-10 No records of maintenance for motors and motor-driven equipment are available.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Using nameplate data, prepare an up-to-date list of all motors and pumps used in the facility and list routine maintenance to be performed on each.

  Check regularly for:

  a. Correct motor voltage and amperage
  b. Loose connections and worn contacts
  c. Unbalanced voltages on three-phase motors
  d. Improper grounding
  e. Packing wear
  f. Wear and binding on bearings and drive belts
  g. Proper sequencing of pumps and motors

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Replace worn equipment with more efficient units, if available.

ENERGY AUDIT CHECKLIST

ADMINISTRATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

A-11 Control devices are not inspected on a regular basis.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Routinely check all time clocks and other control equipment for proper operation, correct time and day, and proper programming of on-off set points. Protect from unauthorized adjustment.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Consider using an automated energy management system as an alternative.

ENERGY AUDIT CHECKLIST

ADMINISTRATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

A-12 Conditioned air or heated water is discarded.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

None Practical

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- It is important for a building owner to be aware of heat recovery measures. However, it is not wise to install such equipment without first analyzing the energy characteristics of the building, performance of the hardware, and how it fits into the overall energy plan.

ENERGY AUDIT CHECKLIST

LIGHTING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

L-1 Incandescent lamps are used in offices, work rooms, hallways, and gymnasiums.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Where possible, use a single incandescent lamp of lower wattage rather than two or more smaller lamps of combined higher wattage.
- Discontinue using extended service lamps except in special cases, such as recessed directional lights where short lamp life is a problem.
- Discontinue using multi-level lamps. The efficiency of a single wattage lamp is higher per watt than a multi-level lamp.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Replace nondecorative incandescent lamps with more energy conserving types such as fluorescents in general purpose areas and mercury vapors in large group areas.

ENERGY AUDIT CHECKLIST

LIGHTING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

L-2 In fixtures where fluorescent lamps have been removed, the ballasts have not been disconnected.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Disconnect ballasts that still use significant amounts of energy even though tubes have been removed.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Replace unnecessary tubes with "dummy" types, which draw little current and yet provide uniform lighting effect.

ENERGY AUDIT CHECKLIST

LIGHTING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

L-3 When burned out fluorescent lamps and/or ballasts have been replaced, more efficient lights have not been installed.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- When relamping, replace fluorescent tubes with more efficient and lower wattage types, such as 35-watt instead of 40-watt, to achieve a reduction in electrical energy consumption. Wherever possible, replace burned out ballasts with more efficient lower wattage energy-conserving ballasts.
- Consider not replacing burned out bulbs or lamps and disconnecting ballasts in areas where delamping is possible. For example, in four-lamp fixtures, allow two lamps to remain and disconnect appropriate ballasts.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Install more efficient fluorescent tubes and ballasts in all existing luminaires (fixtures). (Note: Verify that new lamps will work with existing ballasts.)
- Lowering luminaires (fixtures) will increase illumination levels on the task area and may permit a reduction in the number of fixtures or the wattage of lamps.

ENERGY AUDIT CHECKLIST

LIGHTING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

L-4 Lamps and fixtures are not clean.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Establish a regular inspection and cleaning schedule for lamps and luminaires. Dust buildup reduces effectiveness.
- Replace lens shielding that is yellow or that has become hazy with new acrylic lenses that do not yellow.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Replace outdated or damaged luminaires with modern types that are easy to clean.

ENERGY AUDIT CHECKLIST

LIGHTING

CONDITION

☐ EXISTS
☐ DOES NOT EXIST

L-5 Exterior lighting is used.

SUGGESTED O&M OPTIONS

DATE COMPLETED　INITIALS　N.A.

- Replace exterior 150-watt flood lamps with 75-watt flood lamps to reduce consumption yet maintain adequate illumination.
- Eliminate outdoor lighting where practical.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED　N.A.

- Install a control device (i.e., time clock, photocell) to automatically turn off lights when not needed.
- Replace exterior incandescent lamps with more efficient types, such as high pressure sodium or metal halide.

ENERGY AUDIT CHECKLIST

LIGHTING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

L-6 Lights are on in unoccupied areas.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Provide signs instructing occupants to turn off lights when leaving room.
- Organize task areas to eliminate unnecessary illumination.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Rewire switches so that one switch does not control all fixtures in multiple work spaces.
- Provide timer switches in remote or seldom used areas where there will be brief occupancy periods.

ENERGY AUDIT CHECKLIST

LIGHTING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

L-7 Natural lighting is not optimized.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Utilize natural lighting whenever possible.
- Clean walls or repaint with light reflective non-glossy colors.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Install light sensors and dimming equipment, which automatically compensates for varying natural lighting conditions.

ENERGY AUDIT CHECKLIST

LIGHTING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

L-8 Two lamps have not been removed from four-lamp fixtures where possible.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Remove two lamps and disconnect ballasts.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

None Practical

ENERGY AUDIT CHECKLIST

BUILDING ENVELOPE

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

B-1 Improper alignment and operation of windows and doors allows excessive infiltration.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Realign or re-hang windows or doors that do not permit proper closure. In extreme cases, consider permanent sealing of windows.
- Make sure that automatic door closing mechanisms are working properly. Adjust for faster return.
- Replace or repair faulty gaskets in garage or other overhead doors.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Consider resizing exterior doors (i.e., delivery doors), making them smaller to reduce excessive infiltration.
- Add expandable separate enclosures, where practical.
- Install self-closing doors on openings to unconditioned spaces.

(continued)

ENERGY AUDIT CHECKLIST

BUILDING ENVELOPE

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

(continued)

- Install a switch on overhead doors that prevents activation of heating/cooling units when door is open.
- Install vestibule doors at major entrances.

ENERGY AUDIT CHECKLIST

BUILDING ENVELOPE

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

B-2 Ceiling/roof insulation is inadequate or has been water damaged.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Before replacing water damaged insulation, repair roof where required.
- Verify that vapor barrier faces the conditioned space and is intact.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- Add new insulation to meet recommended standard. (Check the cost effectiveness of this measure particularly if the facility is over three stories.)

ENERGY AUDIT CHECKLIST

BUILDING ENVELOPE

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

B-3 Weather stripping and caulking around windows, doors, conduits, piping, exterior joints, or other areas of infiltration are worn, broken, or missing.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Use quality weather stripping and caulking to ensure that all areas of infiltration are sealed.
- Replace broken or cracked windows. (Air leakage is most evident when wind is blowing against the side of the building.)

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Where practical, cover all windows and through-the-wall cooling units when not in use. Specially designed covers can be obtained at relatively low cost.
- In areas with constant strong winds, consider installing wind screens to protect exterior doors from direct blast of prevailing winds. Screens

(continued)

ENERGY AUDIT CHECKLIST

BUILDING ENVELOPE

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

(continued)

can be opaque (constructed inexpensively from concrete block) or transparent (constructed of metal framing with armored glass). Careful positioning is necessary for infiltration control.

ENERGY AUDIT CHECKLIST

BUILDING ENVELOPE

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

B-4 Excessive expanses of glass exist on exterior walls.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A

- When replacing windows, replace with thermopanes, utilizing the same casings.
- Keep curtains and drapes closed in unoccupied spaces.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- Totally or partially insulate windows. Consider replacing windows with walls.
- Install double pane windows.
- Consider adding reflective or heat absorbing film to minimize solar gain in summer and heat loss in winter. (Note: Any window film reduces natural lighting and winter solar gain.)

(continued)

ENERGY AUDIT CHECKLIST

BUILDING ENVELOPE

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

(continued)

- Consider installation of adjustable outdoor shading devices.

463

ENERGY AUDIT CHECKLIST

BUILDING ENVELOPE

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

B-5 There is no insulation between conditioned and unconditioned spaces.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

None Practical

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Insulate between heated/cooled spaces and unconditioned or outside areas such as parking garages, porticos, storage, basements, and attics.

ENERGY AUDIT CHECKLIST

VENTILATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

V-1 An excessive quantity of outdoor air is used to ventilate the building.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Reduce outdoor air quantity to the minimum allowed by codes by adjusting outdoor air dampers during hours of occupancy.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Replace old style dampers with new high quality opposed-blade models with better close-off ratings.

ENERGY AUDIT CHECKLIST

VENTILATION

CONDITION

☐ EXISTS

☐ DOES NOT EXIST

V-2 Outdoor air intake dampers open when building is unoccupied.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Close outdoor air dampers when building is unoccupied. Be sure dampers have proper seals and adjust to ensure complete closure.
- Where codes permit, close outdoor air dampers during first and last hours of occupancy to permit fast warm-up and cool-down.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- Install controls that will automatically close dampers during unoccupied periods.

ENERGY AUDIT CHECKLIST

VENTILATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

V-3 Ventilation systems are not utilized for natural cooling capability.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Whenever possible, use outside air for cooling rather than using refrigeration. (Use economizer cycle, if available.)

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Install an economizer cycle with enthalpy control to optimize use of outside air for cooling.

ENERGY AUDIT CHECKLIST

VENTILATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

V-4 Exhaust system operation is not programmed.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A

- Discontinue use of unnecessary exhaust fans.
- Rewire toilet exhaust fans to operate only when lights are on. (Fans are often wired in reverse. Correct as needed.)
- Schedules should be established so that exhaust fans run only when needed.
- Consider grouping smoking and other areas with similar exhaust requirements so that they may be served by one exhaust system.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- Install time clocks or other controls to shut off exhaust system when not needed (when permitted by code).
- Install a rheostat in series with exhaust fan to modulate fan speed so that no more than the necessary amount of air will be exhausted.

(continued)

ENERGY AUDIT CHECKLIST

VENTILATION

CONDITION

☐ EXISTS

☐ DOES NOT EXIST

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

(continued)

- Install chemical or electronic odor or particulate remover to reduce the need for using outside air for ventilation.
- Install controlled or gravity dampers on all exhaust ducts to close ducts when fan is not operating.

ENERGY AUDIT CHECKLIST

VENTILATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

V-5 Return outdoor air and exhaust dampers are not sequencing properly.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A

- Adjust damper linkage.
- Be sure damper motors are operating properly.
- Readjust position indicators to accurately indicate damper positions.
- Reset linkage or replace dampers if blades do not close tightly.
- Close all outdoor air intake dampers when equipment is shut off and when building is unoccupied.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- Replace old style dampers with new high quality opposed-blade models with better close-off ratings.

ENERGY AUDIT CHECKLIST

VENTILATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

V-6 During heating season, temperature of airflow to space feels too cold.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Raise supply temperature to a minimum of 60°F in interior zones and 65°F in perimeter zones during winter. Be sure to lower the supply temperature to 55°F during the cooling season. (Check local codes.)
- Reduce air volume to prevent a draft effect during heating season.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

None Practical

ENERGY AUDIT CHECKLIST

VENTILATION

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

V-7 Airflow to space feels unusually low or is inconsistent from one space to another.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Utilize ductwork access openings to check for any obstructions such as loose hanging insulation (in lined ducts), loose turning vanes and accessories, and closed volume and fire dampers. Adjust, repair, or replace as necessary.
- Inspect all room air outlets and inlets (diffusers, registers, and grilles). They should be kept clean and free of all dirt and obstructions. Clean and remove obstructions as necessary.
- Clean or replace dirty or ineffective filters on a regular basis.
- Post signs instructing occupants not to place objects where they will obstruct airflow.
- Consider rebalancing system.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

None Practical

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-1 Multiple boilers or heaters fire simultaneously.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Adjust controls so that boiler #2 will not fire until boiler #1 can no longer satisfy the demand.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Purchase and install automatic staging controls if applicable.

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS
☐ DOES NOT EXIST

H-2 Stack temperature appears excessively high (greater than 400°F plus room temperature).

SUGGESTED O&M OPTIONS

DATE COMPLETED
INITIALS
N.A.

- Ensure that proper amount of air for combustion is available in furnace room.
- Examine and clean air intake filters.
- Perform flue gas analysis on a regular basis to ensure proper air-to-fuel ratio.
- If furnace is over-firing, verify that spuds and nozzles are properly sized. Also check that fuel pressures are not too high.

NOTE: Checks and maintenance of boiler operations should be performed by qualified personnel. If there are none on the staff of the institution, consideration should be given to obtaining assistance from a service contractor.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED
N.A.

- Purchase kit for flue gas analysis if frequent testing is anticipated.

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-3 Water in heating system is heated when there is no need.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A

- Turn off boiler, pumps, or heat source.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Install control to automatically shut down heat-generating device when outside air temperature reaches 60°F.

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-4 Space temperatures are higher or lower than thermostat settings.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A

- Recalibrate thermostat.
- Blow out moisture, oil, and dirt from pneumatic lines (for pneumatic systems); clean contacts if electrical control system.
- Recalibrate controllers.
- Ensure that control valves and dampers are modulated properly.
- Ensure that heat-generating device is producing heat and that heat distribution to the space is unobstructed.
- Make sure air intake volume is not excessive.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- For electric control systems, install preset solid state thermostats that do not require calibration.

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-5 Heating system's hot water temperature feels excessively hot during periods of mild weather.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Experiment with hot water temperature reduction until an acceptable comfort level is reached.
- Make sure reset controls work properly.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Purchase and install automatic temperature controls to schedule heating water temperature according to outside temperature.

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS
☐ DOES NOT EXIST

H-6 Condensate from street steam is being discharged to sewer drain.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

None Practical

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Install pump to return condensate to boiler or return condensate by gravity if possible. Condensate can also be used to heat domestic water or boiler combustion air prior to its return to the boiler feedwater system.

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-7 Heating pilot lights are on during cooling season.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Turn pilots off. (Enter shut-off and turn-on dates in the log book and post a notice in the boiler/furnace room.)

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Replace worn units with new electronic ignition models to avoid unnecessary fuel consumption.

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-8 Steam radiators or other steam equipment fail to heat, or operate erratically.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A

- Check the temperature of the pipe on the downstream side of steam traps. If it is excessively hot, the trap probably is passing steam. This can be caused by dirt in the trap, a valve off the stem, excessive steam pressure, or worn trap parts (especially valves and seats). If the pipe is moderately hot (as hot as a hot water pipe), it probably is passing condensate, which it should. If it is cold, the trap is not working at all and should be replaced or repaired. Initiate a steam trap maintenance program.
- Clean or replace thermostatic control valves on radiators.
- Check air vent valve. If it is not operating properly, replace.
- If thermostatic trap is malfunctioning, clean or replace bellows element.

(continued)

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

None Practical

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS

☐ DOES NOT EXIST

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

(continued)

- Water pockets may be obstructing steam flow. Correct by repitching or rerouting pipes.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-9 Steam, condensate, and heating water piping insulation are in disrepair or missing.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A

- Inspect pipes for broken or missing insulation. Repair or replace as needed.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- Install additional pipe insulation in accordance with design specifications and energy conservation codes.

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-10 Operation of oil burner is accompanied by excessive smoke and sooting.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Inspect burner nozzles for wear, dirt, and incorrect spray angles. Clean and adjust as necessary.
- Verify that oil is flowing freely and that oil pressure is correct.
- Perform flue gas analysis to set proper air-to-fuel ratio.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Purchase kit for flue gas analysis if frequent testing is anticipated.

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-11 Soot and odors are detected in areas where they are not expected.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Heat exchanger may have burned out. Replace.
- Stack draft may be inadequate. Clean and correct as necessary.
- Perform flue gas analysis to obtain proper air-to fuel ratio.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- Purchase kit for flue gas analysis if frequent testing is anticipated.

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-12 Evidence indicates faulty or inefficient boilers or furnaces.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Remove scale deposits, accumulation of sediment, and boiler compounds on waterside surfaces. Examine and treat rear portion of boiler (the area most susceptible to scale formation).
- Remove soot from tubes.
- Observe the fire when the unit shuts down. If the fire does not cut off immediately, it could indicate a faulty solenoid valve. Repair or replace as necessary.
- Inspect all boiler insulation, refractory, brickwork, and boiler casings for hot spots and air leaks. Repair and seal as necessary.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Replace dangerous or ineffective units with more efficient modular type units. (Note: Do not install oversize unit.)
- If applicable, install baffle-type devices in the tubes to improve efficiency.

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-13 Air is humidified.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Discontinue or reduce humidification where possible.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

None Practical

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS

☐ DOES NOT EXIST

H-14 Burner short-cycles.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Hot water temperature limit switch may be set too low. Reset as required.
- Thermostat may be faulty. Replace if necessary.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

None Practical

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-15 Combustion air to boiler/furnace is not preheated.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

None Practical

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- Utilize heat from flue gas to preheat combustion air by means of a heat recovery device.

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-16 Hot water radiation units fail to operate.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Radiators are air-locked. Open air vents and bleed off air until water appears.
- Bleed off water in pneumatic air lines if necessary. (Pneumatic lines may be frozen.) Check for air leaks.
- Repair faulty valves.
- Repair or replace faulty thermostats.
- Hot water pump or booster pump may not be functioning. Repair or replace as necessary.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

None Practical

ENERGY AUDIT CHECKLIST

HEATING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

H-17 Radiators, convectors, baseboards, and finned-tube heaters are not providing sufficient heat.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Boiler temperature may have dropped. Correct as necessary.
- Bleed air from units.
- Establish a systematic cleaning schedule.
- Remove items obstructing discharge grilles.
- Bleed off water in pneumatic air lines if necessary. (Pneumatic lines may be frozen.) Check for air leaks.
- Repair faulty valves.
- Repair or replace faulty thermostats.
- Hot water pump or booster pump may not be functioning. Repair or replace as necessary.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

None Practical

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS
☐ DOES NOT EXIST

C-1 Space temperature is higher or lower than thermostat setting.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Recalibrate space thermostat.
- Blow out moisture, oil, and dirt from pneumatic lines (for pneumatic control system). Clean contacts on electric control systems.
- Recalibrate controllers.
- Verify that control valves and dampers modulate properly, especially the economizer section of the system.
- Limit excessive outdoor air intake when not operating economizer cycle.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- For electric control systems, install preset solid state thermostats that do not require calibration.

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

C-2 Chiller is operating during cold weather to provide air conditioning.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A

None Practical

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- Provide a water interchange system injecting cooling tower condenser water directly into the system's chilled water circuits. Except for pumping and cooling tower fan horsepower, this provides free cooling. Special care must be taken in treating and filtering condenser water.
- If system is forced air, using DX coils and air-cooled condenser, install economizer cycle to obtain free cooling.

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

C-3 Reheat coils are used to maintain zone temperatures.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

None Practical

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Convert to variable air volume system if the reheat coils are not necessary to supply heat during the heating season.

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

C-4 Multiple air-conditioning compressors start at the same time.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A

- Adjust electric controls to stage compressor operation properly.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- Should automatic controls not exist, purchase and install. This will allow compressor #2 to cut in when compressor #1 can no longer satisfy space conditioning load.

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

C-5 Building utilizes a dual duct or multi-zone system.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

None Practical

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Convert dual duct or multi-zone systems to variable air volume if building has a separate heating system.
- Install controls to automatically reset hot and cold deck temperatures.

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

C-6 Insulation on cooling line pipes and ducts appears inadequate.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A

- Repair or replace damaged insulation.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- Insulate all delivery lines and ducts in accordance with recommended R values.

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS
☐ DOES NOT EXIST

C-7 Air-conditioning load trips circuit breaker on extremely warm days.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Tighten wire lugs if loose.
- Replace defective circuit breakers.
- Clean condenser on air-cooled systems.
- Clean scale buildup in condenser on water-cooled systems.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Consider installing insulated underground storage tank that would allow night operation of chiller when electrical demand is low. This reservoir tank would be a source of supply of chilled water for daytime operation. Chiller would not be operated during the day.

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS
☐ DOES NOT EXIST

C-8 Air of inadequate volume or temperature is being discharged through grilles.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Defrost evaporator coil if iced. Determine cause of icing and correct.
- Clean evaporator coil, fins, and tubes.
- Clean or replace air filters.
- Fire damper may be closed. Open and replace fusible link if necessary.
- Balancing damper may have slipped and closed. Open to correct position and tighten wing nut.
- If fan is rotating backwards, reverse rotation by reversing electrical contacts.
- Clean condenser coil and/or water tower nozzles.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A

- Install differential pressure-sensing switches to alarm when airflow drops significantly.

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

C-9 Refrigeration condensers or coils are dirty, clogged and/or not functioning efficiently.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Determine if normal operating temperatures and pressures have been identified and if all gauges are checked frequently to ensure design conditions are being met.
- Increased system pressure may be due to dirty condensers, which will decrease system efficiency. High discharge temperatures often are caused by defective or broken compressor valves. Repair or adjust as required.
- Inspect the liquid line leaving the strainer. If it feels cooler than the liquid line entering the strainer, it is clogged. It is very badly clogged if frost or sweat is visible at the strainer outlet. Clean as required.
- Clean coils and/or other elements as needed on a scheduled basis. Include dehumidification coils.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

None Practical

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

C-10 Chilled water piping, valves, and fittings are leaking.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Repair joint or piping leaks.
- Repair or replace valves.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

None Practical

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

C-11 Chiller operation is not optimized. (Listen for short-cycling.)

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Raise chilled water supply temperature. Note: This is especially important if system was designed for a 75°F space temperature and the space setting has been raised to 78°F for energy conservation purposes.
- Remove scale deposits from condensers.
- Check refrigerant charge.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Reduce peak loads with electric load limiters. (This option saves money, but not energy.)

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

C-12 Refrigeration compressor short-cycles.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Refrigerant charge is low or refrigerant is leaking. Find and repair leak. Recharge system.
- Repair electrical control circuit if required.
- Reset high/low pressure control differential settings if needed.
- Liquid line solenoid valve may be leaking. Repair or replace.
- Evaporation coil may be iced up or dirty. Defrost and clean.
- If frost is detected on the liquid line strainer, it is clogged. Clean strainer.
- Clean condenser coil.

(continued)

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

None Practical

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

(continued)

- If condenser is a cooling tower, ascertain if spray nozzles are plugged. Make sure water flow is unobstructed. Clear tower of leaves and debris.
- Remove scale deposits from shell/tubes on water condensers.
- Repair suction valves in compressor, if needed.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

ENERGY AUDIT CHECKLIST

COOLING

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

C-13 Refrigeration compressor runs continually. (Direct expansion systems.)

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Contacts in starter circuits of controls may be fused. Repair and replace as necessary.
- Bubbles in sight glass indicate low refrigerant charge. Repair leaks and recharge.
- Refrigerant charge may be too high. Check discharge pressure and purge excess.
- Compressor valves may be leaking. Overhaul compressor.
- Liquid line solenoid valve may be stuck open. Repair or replace.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Load may be greater than design. Consider replacing with chiller and water-cooled condenser system.

ENERGY AUDIT CHECKLIST

WATER

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

W-1 Storage tanks, piping, and water heaters are utilized inefficiently.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Replace damaged or missing insulation.
- Reduce hot water temperature to 105°F – 115°F where allowed by code.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Install insulation on all hot water lines and storage tanks.
- Install a small domestic hot water heater to maintain desired temperature in water storage tank. This could eliminate the need for operating one of the large space heating boilers during summer months.
- Install decentralized water heating.

ENERGY AUDIT CHECKLIST

WATER

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

W-2 Drips or leaks are evident in hot water systems.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Repair all leaks, including those of the faucets and pumps.

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

None Practical

ENERGY AUDIT CHECKLIST

WATER

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

W-3 Electric water heater has no time restrictions on heating cycle.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

- Utilize "vacation cycle" on water heater when not needed during extended periods. (Note: Complete deactivation could cause leaks.)

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Limit the duty cycle with a time clock or other control devices to avoid adding the water heating load to the building during peak electrical demand periods. (Additional hot water storage capacity may be required.)

ENERGY AUDIT CHECKLIST

WATER

CONDITION

☐ EXISTS ☐ DOES NOT EXIST

W-4 Devices to conserve heated water have not been utilized where practical.

SUGGESTED O&M OPTIONS

DATE COMPLETED INITIALS N.A.

None Practical

SUGGESTED ENERGY MEASURES: (RETROFIT)

TO BE CONSIDERED N.A.

- Install mixing valves.
- Replace standard faucets with self-closing, flow restrictor types. (Note: Highly mineralized water or water containing sediment can cause blockages.)
- Install a solar water heater to assist in meeting building hot water demand. This will reduce significantly consumption of traditional energy fuels in facilities that are large users of hot water.

CONDITION SUMMARY

CONDITION SUMMARY

The Condition Summary pages are keyed to the Energy Audit Checklist (e.g., L-7 is the seventh item in the lighting section of the Checklist). With the summary pages, quick access can be made to information contained in the completed Checklist. Also, the summary pages are a standard part of the Energy Audit Report.

CONDITION SUMMARY PAGE

ADMINISTRATION

☐ A-1 Thermostats on heating/cooling units are vulnerable to occupant adjustment.
☐ A-2 Thermostat settings have not been adjusted for change in seasons.
☐ A-3 Unoccupied or little used areas are heated or cooled unnecessarily.
☐ A-4 Off-hour activities are scheduled.
☐ A-5 Building temperatures are not adjusted for unoccupied periods.
☐ A-6 Heating/cooling equipment is operating in lobbies, corridors, vestibules and/or other public areas.
☐ A-7 Heating/cooling equipment is started before occupants arrive and/or is operating during last hour of occupancy.
☐ A-8 Use of equipment associated with laundry and custodial services coincides with heavy electrical demand periods.
☐ A-9 Blinds and curtains are not used to help insulate the building.
☐ A-10 No records of maintenance for motors and motor-driven equipment are available.
☐ A-11 Control devices are not inspected on a regular basis.
☐ A-12 Conditioned air or heated water is discarded.

LIGHTING

☐ L-1 Incandescent lamps are used in offices, work rooms, hallways, and gymnaziums.
☐ L-2 In fixtures where fluorescent lamps have been removed, the ballasts have not been disconnected.
☐ L-3 When burned out fluorescent lamps and/or ballasts have been replaced, more efficient lights have not been installed.
☐ L-4 Lamps and fixtures are not clean.
☐ L-5 Exterior lighting is used.
☐ L-6 Lights are on in unoccupied areas.
☐ L-7 Natural lighting is not optimized.
☐ L-8 Two lamps have not been removed from four-lamp fixtures where possible.

BUILDING ENVELOPE

☐ B-1 Improper alignment and operation of windows and doors allows excessive infiltration.
☐ B-2 Ceiling/roof insulation is inadequate or has been water damaged.
☐ B-3 Weather stripping and caulking around windows, doors, conduits, piping, exterior joints, or other areas of infiltration are worn, broken, or missing.
☐ B-4 Excessive expanses of glass exist on exterior walls.
☐ B-5 There is no insulation between conditioned and unconditioned spaces.

VENTILATION

☐ V-1 An excessive quantity of outdoor air is used to ventilate the building.
☐ V-2 Outdoor air intake dampers open when building is unoccupied.
☐ V-3 Ventilation systems are not utilized for natural cooling capability.
☐ V-4 Exhaust system operation is not programmed.
☐ V-5 Return outdoor air and exhaust dampers are not sequencing properly.
☐ V-6 During heating season, temperature of airflow to space feels too cold.
☐ V-7 Airflow to space feels unusually low or is inconsistent from one space to another.

HEATING

☐ H-1 Multiple boilers or heaters fire simultaneously.
☐ H-2 Stack temperature appears excessively high (greater than 400°F plus room temperature).
☐ H-3 Water in heating system is heated when there is no need.
☐ H-4 Space temperatures are higher or lower than thermostat settings.
☐ H-5 Heating system's hot water temperature feels excessively hot during periods of mild weather.
☐ H-6 Condensate from street steam is being discharged to sewer drain.
☐ H-7 Heating pilot lights are on during cooling season.
☐ H-8 Steam radiators or other steam equipment fail to heat, or operate erratically.
☐ H-9 Steam, condensate, and heating water piping insulation are in disrepair or missing.
☐ H-10 Operation of oil burner is accompanied by excessive smoke and sooting.
☐ H-11 Soot and odors are detected in areas where they are not expected.
☐ H-12 Evidence indicates faulty or inefficient boilers or furnaces.
☐ H-13 Air is humidified.
☐ H-14 Burner short-cycles.
☐ H-15 Combustion air to boiler/furnace is not preheated.
☐ H-16 Hot water radiation units fail to operate.
☐ H-17 Radiators, convectors, baseboards, and finned-tube heaters are not providing sufficient heat.

COOLING

☐ C-1 Space temperature is higher or lower than thermostat setting.
☐ C-2 Chiller is operating during cold weather to provide air conditioning.
☐ C-3 Reheat coils are used to maintain zone temperatures.
☐ C-4 Multiple air-conditioning compressors start at the same time.
☐ C-5 Building utilizes a dual duct or multi-zone system.
☐ C-6 Insulation on cooling line pipes and ducts appears inadequate.
☐ C-7 Air-conditioning load trips circuit breaker on extremely warm days.
☐ C-8 Air of inadequate volume or temperature is being discharged through grilles.
☐ C-9 Refrigeration condensers or coils are dirty, clogged and/or not functioning efficiently.
☐ C-10 Chilled water piping, valves, and fittings are leaking.
☐ C-11 Chiller operation is not optimized. (Listen for short-cycling.)
☐ C-12 Refrigeration compressor short-cycles.
☐ C-13 Refrigeration compressor runs continually. (Direct expansion systems.)

WATER

☐ W-1 Storage tanks, piping, and water heaters are utilized inefficiently.
☐ W-2 Drips or leaks are evident in hot water systems.
☐ W-3 Electric water heater has no time restrictions on heating cycle.
☐ W-4 Devices to conserve heated water have not been utilized where practical.

EVALUATION OF POTENTIAL FOR ENERGY CONSERVATION MEASURES

EVALUATION OF POTENTIAL FOR ENERGY CONSERVATION MEASURES

This evaluation is patterned on the 1976 ASHRAE Systems Handbook, Chapter 1, and the Energy Audit Procedures published by the Ohio Board of Regents in June 1978.

A Relative Importance Factor (RIF) ranging from 15 to 35 is assigned to each of the five items listed. Within each, conditions are described and a Weighting Factor (WF) assigned to each condition. The evaluation of the building's potential for energy conservation measures is based on the sum of the products of the RIFs and WFs. The higher this value, the greater the potential for energy savings.

Since energy audits are intended to make relative comparisons, it is essential that conformity be maintained. Therefore, neither the RIF nor the WF are to be altered. Determine the Weighting Factor as follows:

a. Building Envelope (RIF:15)

Percentage of glass area can be estimated by dividing the glass area in a typical wall by the total wall area, or by dividing the value in the Energy Inventory Part 2.C by Part C.3. Large or low infiltration can be determined by noting fit-up of outside doors and windows in their frames. Tight-fitting doors and windows denote low infiltration, and loose fit-up denotes high infiltration.

	WF
Buildings over 40% glass and large infiltration	1.0
Buildings over 40% glass	0.9
Buildings with large infiltration	0.8
Buildings under 40% glass	0.7
Buildings with low infiltration	0.6
Buildings under 15% glass	0.5

b. Lighting (RIF:15)

To determine power usage for lighting in watts/ft², add the wattage of all lamps in the building and divide by the gross floor area of the building, as in Energy Inventory Part E, Section a.3.

	WF
Lighting over 3 W/ft²	1.0
Lighting 2 to 3 W/ft²	0.9
Lighting 1 to 2 W/ft²	0.8
Lighting reduced by changes in switching	0.7
Lighting that cannot be reduced	0.6

c. HVAC System Type (RIF:35)

Check the type of HVAC system found in the building. If knowledge of the system is not available, obtain the information from the mechanical engineer, blueprints, specifications, nameplates, the local HVAC contractor, or refer to HVAC Systems Technical Materials and References.

	WF
Reheat or dual duct	1.0
Multi-zone or induction units	0.9
Rooftop units, wall units, or unit ventilators	0.8
Fan coil, VAV, or heat and vent system	0.7
Radiation, unit heaters (no fan systems)	0.6

d. Outside Air (RIF:20)

Check the ventilation system for outside air percentage. If knowledge of the system is not available, obtain the information from the mechanical engineer, blueprints, specifications, nameplates, the local HVAC contractor, or refer to Energy Inventory, Part E, Section b.

	WF
75 to 100% outside air	1.0
50 to 75% outside air	0.9
25 to 50% outside air	0.8
10 to 25% outside air	0.7
Infiltration, toilet exhausts only	0.6

e. Fan Energy (RIF:15)

To determine square feet per fan horsepower (hp), divide building gross floor area by total hp of all HVAC and ventilating fans in the building. Hp rating can be found on nameplates of pumps and motors in the air-handling systems, or refer to the Energy Inventory, Part E, Section b.

	WF
Under 200 ft^2/fan hp	1.0
200-600 ft^2/fan hp	0.9
600-1000 ft^2/fan hp	0.8
1000-1500 ft^2/fan hp	0.7
1500-2000 ft^2/fan hp	0.6
Over 2000 ft^2/fan hp	0.5

Complete the following table to determine the energy conservation measure potential index:

	RIF	x WF	= EVALUATION
a. Building Envelope - % Glass and Infiltration	15		
b. Lighting Levels	15		
c. HVAC System Type	35		
d. Ratio Outside Air	20		
e. Fan Energy	15		
Energy conservation measure potential index:			

EVALUATION OF
POTENTIAL FOR SOLAR AND
RENEWABLE RESOURCE MEASURES

EVALUATION OF POTENTIAL FOR SOLAR AND RENEWABLE RESOURCE MEASURES

This evaluation is to be completed in the same manner as the energy conservation measures evaluation in the previous section.

a. Available Insolation (RIF:30)

Available insolation is a function of geographic location and site characteristics. Determine average annual horizontal insolation on a horizontal surface from information provided by the State or from the National Weather Service data for the location. Observe whether the building is shaded or unshaded. (A building whose roof and south-facing wall are approximately more than half-shaded for more than approximately four hours per day should be considered "shaded.") If the building is shaded, note whether there is open, unshaded land available adjacent to the building site.

	WF
Unshaded and 1300 Btu/ft^2 or more	1.0
Unshaded, less than 1300 Btu/ft^2	0.5
Open land and 1300 Btu/ft^2 or more	1.0
Open land, less than 1300 Btu/ft^2	0.5
Shaded, 1300 Btu/ft^2 or more	0.2
Shaded, less than 1300 Btu/ft^2	0.1

b. Fuel Used (RIF:20)

Note the fuel used for space heating, air conditioning, and water heating.

	WF
All electric	1.0
Oil or gas heat, otherwise electric	0.8
Coal heat, otherwise electric	0.4
Oil or gas heat, hot water	0.4
Coal heat, hot water	0.2

c. Building Characteristics (RIF:10)

Refer to the Energy Inventory for the description of building size and shape and the location of heating, air conditioning, and water heating equipment. A "favorable" building is one that is compact (i.e., square or rectangular), in which the equipment is in one location on the roof or adjacent to the south-facing wall. A building that is "fair" would be other than compact (i.e., E-shaped, L-shaped, etc.), in which the equipment is in one location on the roof or adjacent to the south-facing wall; or a building that is compact, but in which the equipment is within five floors of the roof or 50 feet of the south-facing wall. A building that is not compact, in which the equipment is located beyond five floors of the roof and 50 feet of the south-facing wall, is to be characterized as "moderate." A highly irregular building, or one in which equipment is in scattered locations — most of which are more than five floors from the roof or 50 feet from the south-facing wall — is characterized as "poor."

	WF
Favorable	1.0
Fair	0.8
Moderate	0.5
Poor	0.2

d. Roof Characteristics (RIF:10)

Refer to the Energy Inventory for the description of roof pitch, materials, structural materials, and obstructions. Characterize the building as "favorable" if the roof is flat or pitched nearly to the south; if the roofing is built-up, shingled, or otherwise sufficiently durable to withstand mounting and maintaining solar collectors; or if the structural members are strong enough to support additional weight and the roof area is free of obstructions. A "fair" rating would be given a building meeting the above conditions, except that the roof pitch is only approximately in the direction of south or there are roof obstructions. Describe a building as "moderate" if the roof pitch is only approximately toward the south and there are roof obstructions. A building that meets none of these conditions is characterized as "poor."

	WF
Favorable	1.0
Fair	0.8
Moderate	0.5
Poor	0.2

e. Wall Characteristics (RIF:20)

Determine the glass area of the south-facing walls as a percentage of the total wall area, noting the construction material, or refer to Energy Inventory, Part F.5.

	WF
Over 75% glass; masonry	1.0
Over 75% glass; aluminum or metal	0.7
Over 75% glass; wood or other	0.6
25% - 75% glass; masonry	0.7
25% - 75% glass; aluminum or metal	0.6
25% - 75% glass; wood or other	0.4
Under 25% glass; masonry	0.5
Under 25% glass; aluminum or metal	0.3
Under 25% glass; wood or other	0.2

f. Wind Speed (RIF:30)

Determine average monthly wind speed using data supplied by the State, obtained from the National Weather Service, or local records. Note whether there are natural or man-made barriers in the direction of the prevailing winds.

	WF
Greater than 15 mph, no barriers	1.0
Between 10-15 mph, no barriers	0.5
Greater than 15 mph, some obstructions	0.7
Between 10-15 mph, some obstructions	0.3
Less than 10 mph	0.2

Complete the following table to determine the solar and renewable resources potential index:

	RIF	x WF	= EVALUATION
a. Insolation Available	30		
b. Fuel Used	20		
c. Building Characteristics	10		
d. Roof Characteristics	10		
e. Wall Characteristics	20		
f. Wind Speed	30		
Solar and renewable resource measure potential index:			

POTENTIAL ENERGY SAVING CALCULATIONS

POTENTIAL ENERGY SAVING CALCULATIONS

This section presents standard preliminary calculations and calculations used by the energy auditor. These calculations are keyed to the Energy Audit Checklist; however, some calculations are not presented because operation and maintenance procedures and/or energy measures are impractical or impossible for the stated condition.

It must be emphasized that any energy calculation that treats building systems independently cannot give precise results. The simplified models provided here allow a reasonable estimation of energy savings. In several cases, it is not possible to isolate the savings due to a single operation and maintenance (O&M) procedure. It is practical, however, to combine several similar O&Ms and assign a percent system savings. This has been done for appropriate options.

In preparing to compute potential energy savings for each applicable option (or group of options), the auditor should note and record necessary information by checking the "required information" corner of the box. In most cases, this information has already been supplied in the Energy Inventory. The auditor simply needs to re-record it.

When all required data has been recorded, the auditor should proceed in the sequence indicated. Finally, results should be recorded in the blank labeled "Estimated Energy Saved."

PRELIMINARY CALCULATIONS

Since many of the calculations require knowledge of energy consumption for heating and cooling, and since it usually is not possible to isolate these factors from a utility bill, it will be necessary for the auditor to complete two preliminary calculations. These calculations will provide reasonable values to be used repeatedly in estimating energy savings for heating and cooling options listed in the Energy

Audit Checklist. They need to be completed only once. If a building does not utilize air conditioning, it is not necessary to complete the cooling load calculation. (All tables and figures used in the calculations appear together, for convenience, in the Calculation Reference Material section at the end of the Workbook.)

O&M/ENERGY MEASURES

The computational procedures in this section are simplified methods of calculating energy savings. They are not intended to be as accurate as — or replace — a professional engineering audit. Therefore, savings results are only approximate and meant to help in identifying high priority energy conservation options. These savings figures cannot be guaranteed.

Also, the estimated savings of various options cannot be added together to arrive at an overall energy savings value since the building systems interact and the options themselves overlap.

If an estimated annual dollar savings is desired for a given option for which a calculation is provided, simply multiply the annual Btu savings by the dollar value per Btu of the appropriate fuel type. These cost figures can be obtained by calling the suppliers. Again, it must be emphasized that individual dollar savings cannot be added to reflect an overall savings.

PRELIMINARY CALCULATIONS

ENERGY CONSUMPTION FOR HEATING

Required Information:

A. Total Area of Exterior Glass (from Energy Inventory, Part C.2) ____________ sq. ft.

B. Total Area of Exterior Walls Excluding Glassed Areas (from Energy Inventory, Part C.3) ____________ sq. ft.

C. Total Area of Roof Excluding Skylights (from Energy Inventory, Part C.4) ____________ sq. ft.

D. Heat Transmission Coefficient for Walls (Select U value of wall type most closely resembling the building's wall composition from Table 1) ____________ Btu/ft^2/hr/°F

E. Heat Transmission Coefficient for Glass (Select U value of window type most closely resembling the building's windows from Table 2) ____________ Btu/ft^2/hr/°F

F. Heat Transmission Coefficient for Roof (Select U value of roof type most closely resembling the building's roof composition from Table 3) ____________ Btu/ft^2/hr/°F

G. Volume of Air Delivered by Supply Fans (from Energy Inventory, Part E, Section b) ____________ Total cfm

H. Estimated Percentage of Outside Ventilation Air (from Energy Inventory, Part E, Section b) ____________ %

I. Outside Design Temperature (from Energy Inventory, Part B.2) ____________ °F

J. Average Indoor Temperature, Winter (from Energy Inventory, Part B.2) ____________ °F

L. Number of Days in Heating Season (from Table 4; if city is not listed, select data from nearest city) ____________ days

M. Average Outside Temperature for Heating Season (from Table 4; use data listed for city selected in Item L) ____________ °F

Procedures:

1. Compute heat transmission factor (HTF) for walls:

   $\underset{D}{\underline{\qquad}} \times \underset{B}{\underline{\qquad}} = \underline{\qquad}$ Btu/hr/°F

2. Compute HTF for glass:

   $\underset{E}{\underline{\qquad}} \times \underset{A}{\underline{\qquad}} = \underline{\qquad}$ Btu/hr/°F

3. Compute HTF for roof:

   $\underset{F}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} = \underline{\qquad}$ Btu/hr/°F

4. Compute HTF for ventilation air:

   $1.08 \times \underset{G}{\underline{\qquad}} \times \underset{H}{\underline{\qquad}} \div 100 = \underline{\qquad}$ Btu/hr/°F

5. Find total HTF:

   (Add results of Steps 1-4) ______ Btu/hr/°F

6. Find total design heat load:

   $\underset{M}{\underline{\qquad}} \times \underset{K}{\underline{\qquad}} = \underset{(0)}{\underline{\qquad}}$ Btu/hr

7. Determine seasonal heating load:

   $\underset{L}{\underline{\qquad}} \times 24 \times \underset{(0)}{\underline{\qquad}} \times (\underset{J}{\underline{\qquad}} - \underset{M}{\underline{\qquad}}) \div \underset{K}{\underline{\qquad}} = \underline{\qquad}$ Btu/yr

______________________________ Btu/yr

Estimated Seasonal Heating Load

ENERGY CONSUMPTION FOR COOLING

Required Information:

A. Gross Floor Area (from Energy Inventory, Part C.1) ____________ sq. ft.

B. Square Feet Per Ton of Air Conditioning (from Table 5; select the value corresponding to the building type most closely resembling the institution) ____________ ft^2/ton

C. Approximate Power Input (from Table 6; select value corresponding to air-conditioning system found in the building) ____________ total kW/design ton

D. Estimated Hours of Cooling (from Table 7; select value corresponding to the city, or nearest city) ____________ cooling hours

Procedures:

1. Determine amount of air conditioning:

$\underset{A}{\underline{\qquad}} \div \underset{B}{\underline{\qquad}} = \underset{(E)}{\underline{\qquad}}$ tons

2. Compute design cooling load:

$\underset{(E)}{\underline{\qquad}} \times 12{,}000 = \underset{(F)}{\underline{\qquad}}$ Btu/hr

3. Determine power requirement:

$\underset{(E)}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} = \underset{(G)}{\underline{\qquad}}$ kW

4. Compute annual electric energy consumption for cooling:

$\underset{(G)}{\underline{\qquad}} \times \underset{D}{\underline{\qquad}} = \underset{(H)}{\underline{\qquad}}$ kWh/yr

5. Determine seasonal cooling load:

$\underset{(H)}{\underline{\qquad}} \times 3{,}413 = \underline{\qquad}$ Btu/yr

$\underset{\text{Estimated Seasonal Cooling Load}}{\underline{\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad}}$ Btu/yr

O & M / ENERGY MEASURES

POTENTIAL ENERGY SAVING CALCULATIONS A-1

O&M

REQUIRED INFORMATION: Unauthorized Thermostat Adjustment:

A. Total HTF factor (from "Energy Consumption for Heating," Step 5) ______ Btu/hr/°F

B. Number of weeks in heating season (from Table 4) ______ wks/yr

C. Number of weeks in cooling season (from Table 8) ______ wks/yr

D. Estimated hours per week of unauthorized setting of thermostat during heating season ______ hrs/wk

E. Estimated hours per week of unauthorized setting of thermostat during cooling season ______ hrs/wk

F. New thermostat setting for heating season ______ °F

G. Unauthorized thermostat setting for heating season ______ °F

H. New thermostat setting for cooling season ______ °F

I. Unauthorized thermostat setting for cooling season ______ °F

PROCEDURES:

1. Compute heating energy savings:

$$\underset{A}{\underline{\hspace{3em}}} \times \underset{(G - F)}{\underline{\hspace{3em}}} \times \underset{D}{\underline{\hspace{3em}}} \times \underset{B}{\underline{\hspace{3em}}} = \underset{(J)}{\underline{\hspace{3em}}} \text{ Btu/yr}$$

2. Compute cooling energy savings:

$$\underset{A}{\underline{\hspace{3em}}} \times \underset{(H - I)}{\underline{\hspace{3em}}} \times \underset{E}{\underline{\hspace{3em}}} \times \underset{C}{\underline{\hspace{3em}}} = \underset{(K)}{\underline{\hspace{3em}}} \text{ Btu/yr}$$

3. Total heating and cooling savings: $\underset{(J)}{\underline{\hspace{3em}}} + \underset{(K)}{\underline{\hspace{3em}}} = \underline{\hspace{3em}}$ Btu/yr

______________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Implementation of suggested energy measures will result in approximately the same amount of savings as suggested O&M options. Record savings computed above in blank below.

______________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS A-2

O&M

REQUIRED INFORMATION: Thermostat Adjustments:

A. Total HTF factor (from "Energy Consumption for Heating," Step 5) ______ Btu/hr/°F

B. Number of weeks in heating season (from Table 4) ______ wks/yr

C. Number of weeks in cooling season (from Table 8) ______ wks/yr

D. Hours per week heating system has operated at higher setting (estimated) ______ hrs/wk

E. Hours per week cooling system has operated at lower setting (estimated) ______ hrs/wk

F. Unadjusted thermostat setting for heating season ______ °F

G. Unadjusted thermostat setting for cooling season ______ °F

PROCEDURES:

1. Compute heating energy savings:

$$\underset{A}{\underline{\qquad}} \times \underset{(F - 68)}{\underline{\qquad}} \times \underset{D}{\underline{\qquad}} \times \underset{B}{\underline{\qquad}} = \underset{(H)}{\underline{\qquad}} \text{ Btu/yr}$$

2. Compute cooling energy savings:

$$\underset{A}{\underline{\qquad}} \times \underset{(78 - G)}{\underline{\qquad}} \times \underset{E}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} = \underset{(I)}{\underline{\qquad}} \text{ Btu/yr}$$

3. Total heating and cooling savings: $\underset{(H)}{\underline{\qquad}} + \underset{(I)}{\underline{\qquad}} = \underline{\qquad}$ Btu/yr

______________________________ Btus
(Est. Energy Savings)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Implementation of suggested energy measure will result in approximately the same amount of savings as suggested O&M options. Record savings computed above in blank below.

______________________________ Btus
(Est. Energy Savings)

POTENTIAL ENERGY SAVING CALCULATIONS A-3

O&M

REQUIRED INFORMATION: Conditioning of Unoccupied Spaces:

A. Total HTF factor (from "Energy Consumption for Heating, Step 5) ______ Btu/hr/°F

B. Number of weeks in heating season (from Table 4) ______ wks/yr

C. Average winter indoor temperature (from Energy Inventory, Part B.2) ______ °F

D. Gross floor area of building (from Energy Inventory, Part C.1) ______ sq. ft.

E. Gross floor area of unoccupied space (estimated) ______ sq. ft.

F. Annual Btu consumption for cooling season (from "Energy Consumption for Cooling, Step 5) ______ Btu/yr

G. New set-back temperature for heating season ______ °F

H. Hours per week temperature will remain at new set-back point (estimated) ______ hrs/wk

I. Sum of gross wall and roof areas (from Energy Inventory, Parts C.3 and C.4) ______ sq. ft.

J. Sum of exterior wall and roof areas enclosing unoccupied space (estimated) ______ sq. ft. (Note: If unoccupied space has no exterior wall and is not located on top floor, it should not require heating.)

PROCEDURES:

1. Compute heating energy savings:

$$\underset{A}{\underline{\hspace{3em}}} \times \underset{(C - G)}{\underline{\hspace{3em}}} \times \underset{H}{\underline{\hspace{3em}}} \times \underset{B}{\underline{\hspace{3em}}} \times \underset{J}{\underline{\hspace{3em}}} \div \underset{I}{\underline{\hspace{3em}}} = \underset{(K)}{\underline{\hspace{3em}}} \text{ Btu/yr}$$

2. Compute cooling energy savings:

$$\underset{F}{\underline{\hspace{3em}}} \times \underset{E}{\underline{\hspace{3em}}} \div \underset{D}{\underline{\hspace{3em}}} = \underset{(L)}{\underline{\hspace{3em}}} \text{ Btu/yr}$$

(continued)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Implementation of suggested energy measure will result in approximately the same amount of savings as suggested O&M options. Record savings computed above in blank below.

______________________________ Btus
(Est. Energy Saved)

O&M

REQUIRED INFORMATION: (continued)

3. Total heating and cooling savings:

______ + ______ = ______ Btu/yr
(K) (L)

______________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION:

POTENTIAL ENERGY SAVING CALCULATIONS A-4

O&M

REQUIRED INFORMATION:

Energy Savings Due To Circulation of Air/Water:

A. Total horsepower of motors to be shut down (estimated) ______ hp
B. Total annual hours of system shut down (estimated) ______ hrs/yr
C. Assume loading factor of 75%.

PROCEDURES:

1. Determine electrical energy savings:

______ x 2544 x ______ x 0.75 = ______ Btu/yr
A B (D)

Energy Savings Due To Lowered Fuel Consumption:

2. Determine heating energy savings:
(Use Step 1 in Calculation A-3) ______ Btu/yr
(E)

3. Compute total energy savings:

______ + ______ = ______ Btu/yr
(D) (E)

______________________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Implementation of suggested energy measure will result in approximately the same amount of savings as suggested O&M options. Record savings computed above in blank below.

______________________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS A-5

O&M

REQUIRED INFORMATION:

Thermostat Adjustment During Unoccupied Periods:

A. Total HTF factor (from "Energy Consumption for Heating, Step 5)
______ Btu/hr/°F

B. Number of weeks in heating season (from Table 4) ______ wks/yr

C. Number of hours per week building is unoccupied (estimated)
______ hrs/wk

D. Temperature set back for unoccupied periods ______ °F

PROCEDURES:

1. Compute heating energy savings:

______ x ______ x ______ x ______ = ______ Btu/yr
A B C D (E)

Air Conditioning System Shut-Down:

2. Compute electrical (cooling) energy savings:
(Use Step 1 in Calculation A-4) ______ Btu/yr
(F)

3. Determine total energy savings:

______ + ______ = ______ Btu/yr
(E) (F)

______________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Implementation of suggested energy measure will result in approximately the same amount of savings as suggested O&M options. Record savings computed above in blank below.

______________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS A-7

O&M

REQUIRED INFORMATION: Modifying Heating/Cooling Operation Time:

A. Seasonal heating load (from "Energy Consumption for Heating," Step 7) ______ Btu/yr

B. Seasonal cooling load (from "Energy Consumption for Cooling," Step 5) ______ Btu/yr

C. Number of days in heating season (from Table 4) ______ days/yr

D. Number of days in cooling season (from Table 8) ______ days/yr

PROCEDURES:

1. Compute heating season in hours:

   $24 \times \underset{C}{\underline{\qquad}} = \underset{(E)}{\underline{\qquad}}$ hrs/yr

2. Find heating energy savings:

   $\underset{A}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} \div \underset{(E)}{\underline{\qquad}} = \underset{(F)}{\underline{\qquad}}$ Btu/yr

3. Compute cooling season in hours:

   $24 \times \underset{D}{\underline{\qquad}} = \underset{(G)}{\underline{\qquad}}$ hrs/yr

4. Find cooling energy savings:

   $\underset{B}{\underline{\qquad}} \times \underset{D}{\underline{\qquad}} \div \underset{(G)}{\underline{\qquad}} = \underset{(H)}{\underline{\qquad}}$ Btu/yr

5. Compute total heating and cooling savings:

   $\underset{(F)}{\underline{\qquad}} + \underset{(H)}{\underline{\qquad}} = \underline{\qquad}$ Btu/yr

______________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Implementation of suggested energy measure will result in approximately the same amount of savings as suggested O&M option. Record savings above in blank below.

______________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS A-9

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION:

Window Films and Outdoor Shading Devices: Cooling Energy Savings:

A. Total solar radiation on a south-facing vertical surface (from Table 9) ______ Btu/ft^2/yr

B. Total solar radiation on an east-facing vertical surface (from Table 9) ______ Btu/ft^2/yr

C. Total solar radiation on a west-facing vertical surface (from Table 9) ______ Btu/ft^2/yr

D. Percent possible sunshine (from Table 10) ______ %

E. Shading coefficient of existing window (from Table 11) ______

F. Shading coefficient of new glass with film or shading device (from Table 11) ______

G. Area of south-facing glass (from Energy Inventory, Part C.2) ______ sq. ft.

H. Area of east-facing glass (from Energy Inventory, Part C.2) ______ sq. ft.

I. Area of west-facing glass (from Energy Inventory, Part C.2) ______ sq. ft.

J. Number of weeks in normal cooling season (from Table 8) ______ wks/yr

PROCEDURES:

1. Find difference between shading coefficients:

$\underset{E}{\underline{\qquad}} - \underset{F}{\underline{\qquad}} = \underset{(K)}{\underline{\qquad}}$

2. Determine cooling season as fraction of year:

$\underset{J}{\underline{\qquad}} \div 52 = \underset{(L)}{\underline{\qquad}}$

(continued)

POTENTIAL ENERGY SAVING CALCULATIONS A-9

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: (continued)

3. Determine savings on south wall:

______ x ______ x ______ x ______ x ______ = ______ Btu/yr
D A G (K) (L) (M)

4. Determine savings on east wall:

______ x ______ x ______ x ______ x ______ = ______ Btu/yr
D B H (K) (L) (N)

5. Determine savings on west wall:

______ x ______ x ______ x ______ x ______ = ______ Btu/yr
D C I (K) (L) (O)

6. Determine total cooling energy savings:

______ + ______ + ______ = ______ Btu/yr
(M) (N) (O)

______________________________ Btus
(Est. Energy Saved)

Shading Devices: Heating Energy Savings:

A. Total exterior glass area (from Energy Inventory, Part C.2) ______ sq. ft.

B. U value for existing glass (from Table 2) ______ Btu/hr/°F/ft^2

C. Average indoor temperature during heating season (from Energy Inventory, Part B.2) ______ °F

D. Averate outside temperature during heating season (from Table 4) ______ °F

E. Number of weeks in normal heating season (from Table 4) ______ wks

F. Number of hours per week heating system operates (from Energy Inventory, Part E, Section c.5; add hours) ______ hrs/wk

G. Assume a maximum 30% savings.

(continued)

POTENTIAL ENERGY SAVING CALCULATIONS A-9

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: (continued)

PROCEDURE:

Compute heating energy savings:

$\underset{A}{\underline{\qquad}} \times \underset{B}{\underline{\qquad}} \times \underset{(C - D)}{\underline{\qquad}} \times \underset{E}{\underline{\qquad}} \times \underset{F}{\underline{\qquad}} \times 0.30 = \underset{(H)}{\underline{\qquad}}$ Btu/yr

______________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS L-1

O&M

REQUIRED INFORMATION: Using Single Incandescents:

A. Total wattage of incandescent lamps that could be replaced with lower wattage lamps (estimated) ______ watts

B. Total replacement wattage (estimated) ______ watts

C. Annual usage (from Energy Inventory, Part E, Section a.2) ______ hrs/yr

PROCEDURE:

Compute energy savings:

______ x (______ - ______) x ______ x 3.413 = ______ Btu/yr
A B C D

______________________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Replacing Incandescents:

A. Number of lamps of the same wattage to be replaced (from inspection) ______ lamps

B. Wattage of existing lamps in A (from inspection) ______ watts

C. Wattage of replacement lamps (from manufacturer) ______ watts

D. Annual usage (from Energy Inventory, Part E, Section a.2) ______ hrs/yr

PROCEDURE:

Determine energy savings:

______ x (______ - ______) x ______ x 3.413 = ______ Btu/yr
A B C D

(Note: This procedure must be repeated for each lamp type. Record total savings below.)

______________________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS L-2

O&M

REQUIRED INFORMATION: Disconnecting Ballasts:

A. Assume fluorescent ballasts use a maximum of 20% of rated power requirement of tubes in fixture.

B. Total wattage of removed tubes (estimated) ______ watts

C. Annual usage (from Energy Inventory, Part E, Section a.1) ______ hrs/yr

PROCEDURE:

Compute energy savings from ballast disconnection:

______ x ______ x 3.413 x 0.20 = ______ Btu/yr
B C

______________________________Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Replacing Fluorescents with "Dummy" Types:

A. Number of tubes replaced with "dummy" types (estimated) ______tubes

B. Savings per tube replaced with "dummy" tube (select value from chart below) ______ watts

Lamp Replaced	Savings, Watts
F20	18
F30	50
F48 (Instant Start)	55
F40	68
F96 (HO)	176
F96 (VHO)	328
F96 (Instant Start)	104

C. Annual usage (from Energy Inventory, Part E, Section a.1) ______ hrs/yr

(continued)

POTENTIAL ENERGY SAVING CALCULATIONS L-2

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: (continued)

PROCEDURE:

Determine energy savings:

______ x ______ x ______ x 3.413 = ______ Btu/yr
A B C

____________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS L-3

O&M

REQUIRED INFORMATION:

Replacing All 40-Watt Lamps with 35-Watt Lamps:

A. Assume a 14% savings occurs when 40-watt fluorescents are replaced with an equal number of 35-watt tubes.

B. Total wattage of 40-watt tubes (from inspection) ______ watts

C. Annual usage (from Energy Inventory, Part E, Section a.1) ______ hrs/yr

PROCEDURE:

Compute energy savings:

$\underset{B}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} \times 3.413 \times 0.14 = \underline{\qquad}$ Btu/yr

______________________________ Btus
(Est. Energy Saved)

(Note: For delamping, use second retrofit calculation below.)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Installing More Efficient Tubes/Ballasts:

A. Wattage of existing fixture (from inspection) ______ watts

B. Wattage of new fixture (from manufacturer) ______ watts

C. Number of existing fixtures to be replaced (est.) ______ fixtures

D. Number of replacement fixtures (estimated) ______ fixtures

E. Annual usage (from Energy Inventory, Part E, Section a.1) ______ hrs/yr

PROCEDURES:

1. Find annual energy requirement of existing fixtures:

$\underset{A}{\underline{\qquad}} \times \underset{E}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} = \underset{F}{\underline{\qquad}}$ Wh/yr

2. Find annual energy requirement of replacement fixtures:

$\underset{B}{\underline{\qquad}} \times \underset{D}{\underline{\qquad}} \times \underset{E}{\underline{\qquad}} = \underset{G}{\underline{\qquad}}$ Wh/yr

(continued)

POTENTIAL ENERGY SAVING CALCULATIONS L-3

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: (continued)

3. Determine energy savings:

(______ - ______) x 3.413 = ______ Btu/yr
(F) (G)

______________________________ Btus
(Est. Energy Saved)

Lowering Luminaires:

(Note: Lowering luminaires only results in energy savings if the number of lamps/tubes is reduced by delamping.)

A. Total wattage of removed lamps/tubes (from inspection) ______ watts

B. Annual usage (from Energy Inventory, Part E, Section a.1 or a.2, depending on lamp type) ______ hrs/yr

PROCEDURE:

Determine energy savings:

______ x ______ x 3.413 = ______ Btu/yr
A B

______________________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS L-4

O&M

REQUIRED INFORMATION: Cleaning Lamps/Fixtures:

A. Total interior lighting load (from Energy Inventory, Part E, Section a.4) ______ kW

B. Annual hours of lighting operation (from Energy Inventory, Part E, Section a.1 and/or a.2) ______ hrs/yr

C. Assume a 5% annual savings for routine cleaning.

PROCEDURE:

Determine energy savings:

$\underset{A}{\underline{\qquad}} \times \underset{B}{\underline{\qquad}} \times 3{,}413 \times 0.05 = \underline{\qquad}$ Btu/yr

______________________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION:

POTENTIAL ENERGY SAVING CALCULATIONS L-5

O&M

REQUIRED INFORMATION: Reducing Exterior Load:

A. Total exterior lighting load (from Energy Inventory, Part E, Section a.4) ______ kW

B. Total exterior replacement load (estimated) ______ kW

C. Usage of exterior lighting (estimated) ______ hrs/yr

PROCEDURES:

1. Find difference between existing and replacement loads:

$\underset{A}{\underline{\qquad}} - \underset{B}{\underline{\qquad}} = \underset{(D)}{\underline{\qquad}}$ kW

2. Compute energy savings:

$\underset{(D)}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} \times 3{,}413 = \underline{\qquad}$ Btu/yr

______________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Control Devices:

A. Total exterior lighting load (from Energy Inventory, Part E, Section a.4) ______ kW

B. Hours of exterior lighting use prior to installing control device (estimated) ______ hrs/yr

C. Hours of exterior lighting use after installing control device (estimated) ______ hrs/yr

PROCEDURE:

Compute energy savings:

$(\underset{B}{\underline{\qquad}} - \underset{C}{\underline{\qquad}}) \times \underset{A}{\underline{\qquad}} \times 3{,}413 = \underline{\qquad}$ Btu/yr

______________________ Btus
(Est. Energy Saved)

(continued)

POTENTIAL ENERGY SAVING CALCULATIONS L-5

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: (continued)

Replacing Exterior Incandescents:

A. Number of same wattage lamps (from inspection) _____ lamps

B. Wattage rating of lamps in A (from inspection) _____ watts/lamp

C. Wattage rating of replacement lamps (from manufacturer) _____ watts/lamp

D. Annual hours of operation (estimated) _____ hrs/yr

PROCEDURES:

1. Find power requirement of all lamps of wattage B:

$$\underset{A}{\underline{\qquad}} \times \underset{B}{\underline{\qquad}} = \underset{(E)}{\underline{\qquad}} \text{ watts}$$

2. Find power requirement of replacement lamps:

$$\underset{A}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} = \underset{(F)}{\underline{\qquad}} \text{ watts}$$

3. Determine energy savings:

$$(\underset{(E)}{\underline{\qquad}} - \underset{(F)}{\underline{\qquad}}) \times 3.413 \times \underset{D}{\underline{\qquad}} = \underline{\qquad} \text{ Btu/yr}$$

(Note: This calculation must be repeated for each set of lamps of different wattage. Record total estimated savings below.)

_________________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS L-6

O&M

REQUIRED INFORMATION: Turning Lights Off in Unoccupied Areas:

A. Assume a maximum 5% annual savings.

B. Total interior lighting load (from Energy Inventory, Part E, Section a.4) ______ kW

C. Annual usage (from Energy Inventory, Part E, Section a.1 or a.2, whichever is applicable) ______ hrs/yr

PROCEDURE:

Find annual lighting energy savings:

$\underset{B}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} \times 3{,}413 \times 0.05 = \underline{\qquad}$ Btu/yr

________________ Btus
(Est. Energy Saved)

(continued)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Rewiring Switches:

A. Number of lamps of same wattage rating controlled per circuit (switch) (from inspection) ______ lamps

B. Wattage rating for lamps in A (from inspection) ______ watts/lamp

C. Annual usage of lamps on circuit (estimated) ______ hrs/yr

D. Annual usage of lamps on rewired circuits (estimated) ______ hrs/yr

PROCEDURE:

Determine energy savings:

$\underset{A}{\underline{\qquad}} \times \underset{B}{\underline{\qquad}} \times (\underset{C}{\underline{\qquad}} - \underset{D}{\underline{\qquad}}) \times 3.413 = \underline{\qquad}$ Btu/yr

(Note: Do one circuit (switch group) at a time. Add individual savings to obtain total savings and record below.)

________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS L-6

O&M

REQUIRED INFORMATION: (continued)

Organizing Task Areas:

Assume a maximum 3% annual savings if task lighting is used during non-regular working hours.

PROCEDURE:

Determine maximum annual energy savings:

______ x ______ x 3,413 x 0.03 = ______ Btu/yr
B C

________________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION:

POTENTIAL ENERGY SAVING CALCULATIONS L-8

O&M

REQUIRED INFORMATION: Removing Two Lamps from Four-Lamp Fixtures:

A. Number of disconnected lamps of same wattage in fixtures in which ballasts have also been disconnected (estimated) ______ lamps

B. Wattage of each disconnected lamp in A (estimated) ______watts/lamp

C. Annual usage (from Energy Inventory, Part E, Section a.1) ______ hrs/yr

D. Disconnecting ballast saves an additional 20%.

PROCEDURE:

Determine energy savings:

______ x ______ x ______ x 1.2 x 3.413 = ______ Btu/yr
A B C

____________________________Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION:

POTENTIAL ENERGY SAVING CALCULATIONS B-2

O&M

REQUIRED INFORMATION: Replacing Damaged Insulation:

A. U value for roof (from Table 3) ______ Btu/hr/°F/ft^2

B. Assume 75% greater heat loss through damaged insulation.

C. Water damaged area (estimated) ______ sq. ft.

D. Number of degree days in normal heating season (from Table 12) ______ HDD

E. Number of degree days in normal cooling season (from Table 13) ______ CDD

PROCEDURES:

1. Determine heating energy savings:

$$0.75 \times \underset{A}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} \times 24 \times \underset{D}{\underline{\qquad}} = \underset{(F)}{\underline{\qquad}} \text{ Btu/yr}$$

(continued)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Adding More Insulation:

A. U value for roof (from Table 3) ______ Btu/hr/°F/ft^2

B. Number of degree days in normal heating season (from Table 12) ______ HDD

C. U value for "new" roof (from Table 3) ______ Btu/hr/°F/ft^2

D. Gross roof area (from Energy Inventory, Part C.4) ______ sq. ft.

E. Number of degree days in normal cooling season (from Table 13) ______ CDD

PROCEDURES:

1. Find difference in U values:

$$\underset{A}{\underline{\qquad}} - \underset{C}{\underline{\qquad}} = \underset{(F)}{\underline{\qquad}} \text{ Btu/hr/°F/ft}^2$$

2. Determine heating energy savings:

$$\underset{(F)}{\underline{\qquad}} \times \underset{D}{\underline{\qquad}} \times 24 \times \underset{B}{\underline{\qquad}} = \underset{(G)}{\underline{\qquad}} \text{ Btu/hr}$$

(continued)

POTENTIAL ENERGY SAVING CALCULATIONS B-2

O&M

REQUIRED INFORMATION: (continued)

2. Determine cooling energy savings:

$0.75 \times \underset{A}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} \times 24 \times \underset{E}{\underline{\qquad}} = \underset{(G)}{\underline{\qquad}}$ Btu/yr

3. Find total heating and cooling savings:

$\underset{(F)}{\underline{\qquad}} + \underset{(G)}{\underline{\qquad}} = \underline{\qquad}$ Btu/yr

$\underset{\text{(Est. Energy Saved)}}{\underline{\qquad\qquad\qquad\qquad}}$ Btus

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: (continued)

3. Determine cooling energy savings:

$\underset{(F)}{\underline{\qquad}} \times \underset{D}{\underline{\qquad}} \times 24 \times \underset{E}{\underline{\qquad}} = \underset{(H)}{\underline{\qquad}}$ Btu/yr

4. Find total heating and cooling energy savings:

$\underset{(G)}{\underline{\qquad}} + \underset{(H)}{\underline{\qquad}} = \underline{\qquad}$ Btu/yr

$\underset{\text{(Est. Energy Saved)}}{\underline{\qquad\qquad\qquad\qquad}}$ Btus

POTENTIAL ENERGY SAVING CALCULATIONS B-4

O&M

REQUIRED INFORMATION: Suggested O&M measure for window replacement will save approximately the same amount of energy as double-pane calculation. Record that result in the blank below. No calculation is provided for curtains and drapes.

_____________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Insulating Windows (Heating Energy Savings):

A. U value for existing window (from Table 2) ______ Btu/hr/°F/ft^2

B. R value for new insulation ______Btu/hr/°F/ft^2

C. Number of degree days in normal heating season (from Table 12) ______ HDD

D. Total window area to be replaced with insulation (estimated) ______ sq. ft.

PROCEDURES:

1. Find U value for new space:

$(1 \div \underset{A}{\underline{\qquad}}) + \underset{B}{\underline{\qquad}} = \underset{(E)}{\underline{\qquad}}$

$1 \div \underset{(E)}{\underline{\qquad}} = \underset{(F)}{\underline{\qquad}}$

2. Find difference in U values:

$\underset{A}{\underline{\qquad}} - \underset{(F)}{\underline{\qquad}} = \underset{(G)}{\underline{\qquad}}$

3. Determine heating energy savings:

$\underset{(G)}{\underline{\qquad}} \times \underset{D}{\underline{\qquad}} \times 24 \times \underset{C}{\underline{\qquad}} = \underline{\qquad}$ Btu/yr

_____________ Btus
(Est. Energy Saved)

(continued)

POTENTIAL ENERGY SAVING CALCULATIONS B-4

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: (continued)

Installing Double-Pane Windows (Heating Energy Savings):

A. U value for existing window (from Table 2) ______ Btu/hr/°F/ft^2

B. Number of degree days in normal heating season (from Table 12) ______ HDD

C. U value for new window (from Table 2) ______ Btu/hr/°F/ft^2

D. Total window area for which double panes are to be affixed (estimated) ______ sq. ft.

PROCEDURES:

1. Compute difference in U values:

______ - ______ = ______
A C (E)

2. Determine heating energy savings:

______ x ______ x 24 x ______ = ______ Btu/yr
(E) D B

______________________ Btus
(Est. Energy Saved)

Shading Devices (Heating Energy Savings):

This calculation was used previously in A-9.

PROCEDURES:

1. Use the second retrofit calculation listed in A-9 to calculate savings. Record savings below.
2. If this calculation has already been completed, re-record savings below.

______________________ Btus
(Est. Energy Saved)

(continued)

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: (continued)

Window Films and Outdoor Shading Devices (Cooling Energy Savings):

A. Total solar radiation on a south-facing vertical surface (from Table 9) ______ Btu/ft^2/yr

B. Total solar radiation on an east-facing vertical surface (from Table 9) ______ Btu/ft^2/yr

C. Total solar radiation on a west-facing vertical surface (from Table 9) ______ Btu/ft^2/yr

D. Percent possible sunshine (from Table 10) ______ %

E. Shading coefficient of existing window (from Table 11) ______

F. Shading coefficient of new glass with film or shading device (from Table 11) ______

G. Area of south-facing glass (from Energy Inventory, Part C.2) ______ sq. ft.

H. Area of east-facing glass (from Energy Inventory, Part C.2) ______ sq. ft.

I. Area of west-facing glass (from Energy Inventory, Part C.2) ______ sq. ft.

J. Number of weeks in normal cooling season (from Table 8) ______wks/yr

PROCEDURES:

1. Find difference between shading coefficients:

$\underset{F}{\underline{\quad\quad}} - \underset{E}{\underline{\quad\quad}} = \underset{(K)}{\underline{\quad\quad}}$

2. Determine cooling season as fraction of year:

$\underset{J}{\underline{\quad\quad}} \div 52 = \underset{(L)}{\underline{\quad\quad}}$

(continued)

POTENTIAL ENERGY SAVING CALCULATIONS B-4

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: (continued)

3. Determine savings on south wall:

______ ÷ 100 x ______ x ______ x ______ x ______ = ______ Btu/yr
D A G (K) (L) (M)

4. Determine savings on east wall:

______ ÷ 100 x ______ x ______ x ______ x ______ = ______ Btu/yr
D B H (K) (L) (N)

5. Determine savings on west wall:

______ ÷ 100 x ______ x ______ x ______ x ______ = ______ Btu/yr
D C I (K) (L) (O)

6. Determine total cooling energy savings:

______ + ______ + ______ = ______ Btu/yr
(M) (N) (O)

____________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS B-5

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Insulating Walls or Roofs:

A. U value for existing wall (roof) (from Table 1 or Table 3) ______ Btu/hr/°F/ft²

B. R value for new insulation ______ Btu/hr/°F/ft²

C. Number of heating degree days in normal heating season (from Table 12) ______ HDD

D. Gross wall (roof) area (from Energy Inventory, Part C.3 and/or C.4) ______ sq. ft.

PROCEDURES:

1. Find U value for new wall (roof):

$(1 \div \underset{A}{\underline{\hspace{3em}}}) + \underset{B}{\underline{\hspace{3em}}} = \underset{(E)}{\underline{\hspace{3em}}}$

$1 \div \underset{(E)}{\underline{\hspace{3em}}} = \underset{(F)}{\underline{\hspace{3em}}}$ Btu/hr/°F/ft²

2. Find difference between U values:

$\underset{A}{\underline{\hspace{3em}}} - \underset{(F)}{\underline{\hspace{3em}}} = \underset{(G)}{\underline{\hspace{3em}}}$ Btu/hr/°F/ft²

3. Determine energy savings:

$\underset{(G)}{\underline{\hspace{3em}}} \times \underset{D}{\underline{\hspace{3em}}} \times 24 \times \underset{C}{\underline{\hspace{3em}}} = \underline{\hspace{3em}}$ Btu/yr

$\underset{\text{(Est. Energy Saved)}}{\underline{\hspace{12em}}}$ Btus

(Note: Calculation applies to conditioned spaces adjacent to outside area.)

POTENTIAL ENERGY SAVING CALCULATIONS V-1

O&M

REQUIRED INFORMATION: Reducing Outside Air Intake:

A. Number of hours per week during heating season outside air dampers operate in minimum position (estimated) ______ hrs/wk

B. Length of normal heating season (from Table 4) ______ wks/yr

C. Amount of ventilation air required (from governing codes) ______cfm

D. System's air handling capacity (from Energy Inventory, Part E, Section b) ______ cfm

E. Minimum percent outside air brought into building (from Energy Inventory, Part E, Section b) ______ %

F. Average outside temperature during heating season (from Table 4) ______ °F

G. Average indoor temperature (from Energy Inventory, Part B.2) ______ °F

H. Average outside temperature during cooling season (from Table 8) ______ °F

I. Number of hours per week during cooling season that outside air dampers operate in the "minimum" position (estimated) ______hrs/wk

J. Number of weeks in normal cooling season (from Table 8) ______wks/yr

PROCEDURES:

1. Compute volume of excess air brought into building per minute:

$$(\underset{E}{\underline{\qquad}} \div 100 \times \underset{D}{\underline{\qquad}}) - \underset{C}{\underline{\qquad}} = \underset{(K)}{\underline{\qquad}} \text{ cfm}$$

2. Compute heating energy savings:

$$\underset{(K)}{\underline{\qquad}} \times 1.08 \times \underset{(G - F)}{\underline{\qquad}} \times \underset{A}{\underline{\qquad}} \times \underset{B}{\underline{\qquad}} = \underset{(L)}{\underline{\qquad}} \text{ Btu/yr}$$

(continued)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION:

O&M

REQUIRED INFORMATION: (continued)

3. Compute cooling energy savings:

_____ x 1.08 x _____ x _____ x _____ = _____ Btu/yr
(K) (H - G) I J (M)

4. Find total heating and cooling savings:

_____ + _____ = _____ Btu/yr
(L) (M)

_____________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION:

POTENTIAL ENERGY SAVING CALCULATIONS V-2

O&M

REQUIRED INFORMATION: Closing Dampers During Unoccupied Periods:

A. Average outdoor temperature during heating season (from Table 4) ______ °F

B. Average indoor temperature during heating season (from Energy Inventory, Part B.2) ______ °F

C. Minimum percent outside air admitted into building (from Energy Inventory, Part E, Section b) ______ %

D. System's air handling capacity (from Energy Inventory, Part E, Section b) ______ cfm

E. Number of weeks in normal heating season (from Table 4) ______wks/yr

F. Hours per week during heating season that building is unoccupied (estimated from data in Energy Inventory, Part B.1) ______ hrs/wk

PROCEDURES:

1. Determine quantity of outside air admitted into building:

$$\underset{C}{\underline{\qquad\qquad}} \div 100 \times \underset{D}{\underline{\qquad\qquad}} = \underset{(G)}{\underline{\qquad\qquad}} \text{ cfm}$$

2. Compute system's annual operation:

$$\underset{E}{\underline{\qquad\qquad}} \times \underset{F}{\underline{\qquad\qquad}} = \underset{(H)}{\underline{\qquad\qquad}} \text{ hrs/yr}$$

3. Compute heating energy savings:

$$1.08 \times \underset{(G)}{\underline{\qquad\qquad}} \times \underset{(B - A)}{\underline{\qquad\qquad}} \times \underset{(H)}{\underline{\qquad\qquad}} = \underline{\qquad\qquad} \text{ Btu/yr}$$

______________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Implementation of suggested energy measure will result in approximately the same savings as suggested O&M options. Record savings computed above in blank below.

______________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS V-4

O&M

REQUIRED INFORMATION:

Discontinuing Use of Rescheduling Exhaust Fan Operation:

A. Power of exhaust fans (from Energy Inventory, Part E, Section b) ______ hp

B. Current annual exhaust fan operation (estimated) ______ hrs/yr

C. Adjusted annual exhaust fan operation (estimated) ______ hrs/yr

PROCEDURE:

Compute energy savings:

$$\underset{(B - C)}{\underline{\qquad}} \times \underset{A}{\underline{\qquad}} \times 2545 = \underline{\qquad} \text{ Btu/yr}$$

____________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Implementation of suggested energy measures will result in approximately the same amount of savings as suggested O&M options. Record savings computed above in blank space below.

____________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS H-4

O&M

REQUIRED INFORMATION: Recalibrating Thermostat:

If space temperature is higher than thermostat setting:

A. Determine number of degrees F thermostat is out of calibration (from inspection and measurement) _____ °F

B. Number of weeks in normal heating season (from Table 4) _____wks/yr

C. Operation time of heating system (from Energy Inventory, Part E, Section c.5; add hours/day) _____ hrs/wk

D. Total HTF (from "Energy Consumption for Heating," Step 5) _____ Btu/hr/°F

PROCEDURES:

1. Determine hours of operation per heating season:

_____ x _____ = _____ hrs/yr
B C (E)

2. Compute energy savings:

_____ x _____ x _____ = _____ Btu/yr
D (E) A

(If space temperature is lower than thermostat setting during the heating season, heating energy is probably being saved.)

_______________________Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Implementation of suggested energy measure will result in approximately the same amount of savings as suggested O&M options. Record savings computed above in blank below.

_______________________Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS H-5

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Installing Automatic Temperature Controls:

A. Assume 12% annual energy savings.

B. Seasonal heating load (from "Energy Consumption for Heating," Step 7) ______ Btu/yr

PROCEDURE:

Compute heating energy savings:

______ x 0.12 = ______ Btu/yr
B

____________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS H-6

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Returning Condensate to Boiler:

A. Steam consumption (from Energy Inventory, Part D, Row 5, Column B) ______ lbs/yr

B. Average city water temperature (from Energy Inventory, Part E, Section d.4) ______ °F

C. Condensate temperature (measured) ______ °F

PROCEDURE:

Determine energy savings:

$\underset{A}{\underline{\hspace{2em}}} \times \underset{(C - B)}{\underline{\hspace{2em}}} = \underline{\hspace{2em}}$ Btu/yr

______________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS H-7

O&M

REQUIRED INFORMATION: Turning Pilots Off:

A. Number of identical pilots turned off (from inspection)
______ pilots

B. Amount of gas consumed per hour by one pilot in A (from local utility) ______ ft^3/hr

C. Heat value of gas (from local utility or use 1030) ______ Btu/ft^3

D. Number of hours per year pilot will be turned off (estimated)
______ hrs/yr

PROCEDURE:

Determine energy savings:

$\underset{A}{\_\_\_\_\_\_} \times \underset{B}{\_\_\_\_\_\_} \times \underset{C}{\_\_\_\_\_\_} \times \underset{D}{\_\_\_\_\_\_} = \_\_\_\_\_\_$ Btu/yr

(Note: Repeat this calculation for each pilot light size. Record total savings below.)

______________________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION:

POTENTIAL ENERGY SAVING CALCULATIONS H-8

O&M

REQUIRED INFORMATION: Replacing Steam Traps:

A. Number of traps to be replaced (from inspection) ______ traps

B. Assume 50,000,000 Btu/yr saved per malfunctioning trap of 3/16" orifice diameter and 5 psig steam pressure for a 130-day heating season.

PROCEDURE:

Determine energy savings for trap replacement:

______ x 50,000,000 = ______ Btu/yr
A

____________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION:

POTENTIAL ENERGY SAVING CALCULATIONS H-9

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Adding More Pipe Insulation:

A. Pipe diameter (from inspection) ______ in

B. Length of pipe (estimated) ______ ft

C. Number of weeks per year pipe supplies hot water (from Energy Inventory, Part E, Section c.6) ______ wks/yr

D. Number of hours per week pipe supplies hot water (from Energy Inventory, Part E, Section c.5; add hours) ______ hrs/wk

PROCEDURES:

1. Find heat loss per 10 feet of pipe in A (from Table 14 or Table 15, depending on water temperature in heating system):

   ______ Btu/hr/10 ft

2. Determine energy savings:

   ______ (E) ÷ 10 x ______ B x ______ C x ______ D = ______ Btu/yr

______________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS H-12

O&M

REQUIRED INFORMATION: Routine Cleaning/Maintenance:

A. Assume a 10% energy savings.

B. Seasonal heating load (from "Energy Consumption for Heating," Step 7) ______ Btu/yr

PROCEDURE:

Compute energy savings:

$\underset{B}{\underline{\qquad}} \times 0.10 = \underline{\qquad}$ Btu/yr

______________________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Replacing Inefficient Units:

A. Efficiency of old unit (from manufacturer) ______ %

B. Efficiency of new unit (from manufacturer) ______ %

C. Seasonal heating load (from "Energy Consumption for Heating," Step 7) ______ Btu/yr

PROCEDURE:

Determine energy savings:

$(\underset{B}{\underline{\qquad}} - \underset{A}{\underline{\qquad}}) \div 100 \times \underset{C}{\underline{\qquad}} = \underline{\qquad}$ Btu/yr

______________________________ Btus
(Est. Energy Saved)

(continued)

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: (continued)

Improving Efficiency with Baffles:

A. Seasonal heating load (from "Energy Consumption for Heating," Step 7) ______ Btu/hr

B. Improvement in efficiency: For old boilers (3" tubes), use 0.10.
For new boilers (3" tubes), use 0.03.

PROCEDURE:

Determine energy savings:

______ x ______ = ______ Btu/yr
A B

______________________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Preheating Combustion Air:

A. Assume one cubic foot of combustion air required for each 100 Btus of output.

B. Seasonal heating load (from "Energy Consumption for Heating," Step 7) ______ Btu/yr

C. Number of degrees combustion air can be preheated using heat recovery device (from manufacturer) ______ °F

D. Boiler efficiency (from manufacturer) ______ %

PROCEDURES:

1. Find annual volume of combustion air required:

$$\underset{B}{\underline{\qquad}} \div \underset{D}{\underline{\qquad}} = \underset{(E)}{\underline{\qquad}} \text{ ft}^3/\text{yr}$$

2. Compute heating energy savings:

$$\underset{C}{\underline{\qquad}} \times \underset{(E)}{\underline{\qquad}} \times 0.075 \times 0.24 = \underline{\qquad} \text{ Btu/yr}$$

________________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS C-1

O&M

REQUIRED INFORMATION: Recalibrating Thermostat:

During cooling season, if space temperature is lower than thermostat setting:

A. Number of degrees thermostat is out of calibration (from inspection) ______ °F

B. Number of weeks in cooling season (from Table 8) ______ wks/yr

C. Cooling system operating time (from Energy Inventory, Part E, Section c.5; add hours) ______ hrs/wk

D. Total HTF factor (from "Energy Consumption for Heating," Step 5) ______ Btu/hr/°F

PROCEDURES:

1. Find annual cooling system operation:

   ______ x ______ = ______ hrs/yr
   B C (E)

2. Compute cooling savings:

   ______ x ______ x ______ = ______ Btu/yr
   D (E) A

______________________ Btus
(Est. Energy Saved)

(If space temperature is higher than thermostat setting during the cooling season, energy is probably being conserved, depending on the type of system employed. If a reheat or dual duct system is being used, however, calculate excess energy consumed using above method.)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Implementation of suggested energy measure will result in approximately the same amount of savings as suggested O&M options. Record savings computed above in blank below.

______________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS C-5

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Resetting Hot Deck Temperatures:

A. System's air handling capacity (from Energy Inventory, Part E, Section b) ______ cfm

B. Length of cooling season (from Table 8) ______ wks/yr

C. Length of heating season (from Table 4) ______ wks/yr

D. Hot deck reset in summer (lower temperature 5-10°F ______ °F

E. Hot deck reset in winter (lower temperature 3-6°F) ______ °F

F. Operating time per week (estimated) ______ hrs/wk

PROCEDURES:

1. Determine heating energy saved in summer:

$$\underset{A}{\underline{\qquad}} \times 0.5 \times 1.08 \times \underset{D}{\underline{\qquad}} \times \underset{B}{\underline{\qquad}} \times \underset{F}{\underline{\qquad}} = \underset{(G)}{\underline{\qquad}} \text{ Btu/yr}$$

2. Determine heating energy saved in winter:

$$\underset{A}{\underline{\qquad}} \times 0.5 \times 1.08 \times \underset{E}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} \times \underset{F}{\underline{\qquad}} = \underset{(H)}{\underline{\qquad}} \text{ Btu/yr}$$

3. Determine annual heating energy savings:

$$\underset{(G)}{\underline{\qquad}} + \underset{(H)}{\underline{\qquad}} = \underline{\qquad} \text{ Btu/yr}$$

______________________________ Btus
(Est. Energy Saved)

(continued)

POTENTIAL ENERGY SAVING CALCULATIONS C-5

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: (continued)

Resetting Cold Deck Temperatures:

A. System's air handling capacity (from Energy Inventory, Part E, Section b) ______ cfm

B. Length of cooling season (from Table 8) ______ wks/yr

C. Cold deck reset (raise temperature 3-6°F) ______ °F

D. Operating time per week (estimated) ______ hrs/wk

PROCEDURE:

Determine cooling energy saved:

$\underset{A}{\underline{\hspace{3em}}} \times 0.5 \times 1.08 \times \underset{C}{\underline{\hspace{3em}}} \times \underset{B}{\underline{\hspace{3em}}} \times \underset{D}{\underline{\hspace{3em}}} = \underline{\hspace{3em}}$ Btu/yr

____________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS C-6

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Insulating Chilled Water Lines:

A. Pipe diameter (from inspection) ______ in

B. Length of pipe (estimated) ______ ft

C. Number of weeks per year pipe supplies chilled water (from Energy Inventory, Part E, Section c.6) ______ wks/yr

D. Number of hours per week pipe supplies chilled water (from Energy Inventory, Part E, Section c.5; add hours) ______ hrs/wk

E. Find heat gain per ten feet of pipe in A (from Table 16) ______ Btu/hr/10 ft

PROCEDURE:

Determine energy savings:

$\underset{E}{\underline{\qquad}} \div 10 \times \underset{B}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} \times \underset{D}{\underline{\qquad}} = \underline{\qquad}$ Btu/yr

____________________ Btus
(Est. Energy Saved)

574

POTENTIAL ENERGY SAVING CALCULATIONS C-9

O&M

REQUIRED INFORMATION: Cleaning Condenser Coils:

A. Seasonal cooling load (from "Energy Consumption for Cooling," Step 5) ______ Btu/yr

B. Assume a 10% savings.

PROCEDURE:

Determine cooling energy savings:

______ x 0.10 = ______ Btu/yr
A

______________________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION:

O&M

REQUIRED INFORMATION: Raising Chilled Water Temperature:

A. Assume chiller supply temperature is raised from 45°F to 48°F (3 degrees increase).

B. Seasonal cooling energy load (from "Energy Consumption for Cooling," Step 5) ______ Btu/yr

C. Assume 2% per degree of reset or 6% for a three-degree reset.

PROCEDURE:

Determine cooling energy savings:

______ x 0.06 = ______ Btu/yr
B

______________________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION:

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION:

Replacing Refrigeration System with Water-Cooled Condenser System:

A. Amount of air conditioning (from "Energy Consumption for Cooling," Step 1) ______ tons

B. Approximate power input for existing system (from "Energy Consumption for Cooling," Step C) ______ kW/design ton

C. Approximate power input for water-cooled condenser system (from Table 6) ______ kW/design ton

D. Full-load operating hours (from Table 7; if city is not listed, select value for nearest city in same cooling zone from Figure 1) ______ hrs/yr

PROCEDURES:

1. Find difference in power requirements:

$\underset{B}{\underline{\qquad}} - \underset{C}{\underline{\qquad}} = \underset{(E)}{\underline{\qquad}}$ kW/ton

2. Compute cooling energy savings:

$\underset{(E)}{\underline{\qquad}} \times \underset{A}{\underline{\qquad}} \times \underset{D}{\underline{\qquad}} \times 3{,}413 = \underline{\qquad}$ Btu/yr

______________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS W-1

O&M

REQUIRED INFORMATION: Reducing Hot Water Temperature:

A. Daily per capita hot water consumption (from Table 17) ______ gal/person/day

B. Number of work days per year (estimated from Energy Inventory, Part B.1) ______ days/yr

C. Average number of occupants (estimated from Energy Inventory, Part B.1) ______ occupants

D. Assume energy savings of 8.33 Btu/gal/°F

E. Number of degrees temperature of hot water is to be reduced (estimated) ______ °F

PROCEDURES:

1. Find annual consumption:

$\underset{A}{\underline{\qquad}} \times \underset{B}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} = \underset{(F)}{\underline{\qquad}}$ gal/yr

(continued)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Insulating Pipes:

A. Pipe diameter (from inspection) ______ in

B. Length of pipe in A (estimated) ______ ft

C. Number of weeks pipe supplies hot water (est.) ______ wks/yr

D. Hours per week pipe supplies hot water (est.) ______ hrs/wk

E. Find heat loss per 10 feet of pipe in A (from Table 14 or Table 15, depending on water temperature) ______ Btu/hr/10 ft

PROCEDURE:

Determine energy savings:

$\underset{E}{\underline{\qquad}} \div 10 \times \underset{B}{\underline{\qquad}} \times \underset{C}{\underline{\qquad}} \times \underset{D}{\underline{\qquad}} = \underline{\qquad}$ Btu/yr

______________________ Btus
(Est. Energy Saved)

(continued)

O&M

REQUIRED INFORMATION: (continued)

2. Determine energy savings:

$\underset{(F)}{\underline{\qquad}} \times 8.33 \times \underset{E}{\underline{\qquad}} = \underline{\qquad}$ Btu/yr

______________________ Btus
(Est. Energy Saved)

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: (continued)

Insulating Storage Tank:

A. Surface area of tank (from manufacturer) _____ sq. ft.
B. R value of insulation _____ Btu/hr/°F/ft^2
C. Temperature of hot water in tank (measured) _____ °F
D. Temperature of surrounding air (measured) _____ °F
E. Number of hours per year tank is used (estimated) _____ hrs/yr

PROCEDURE:

Compute energy savings:

$\underset{A}{\underline{\qquad}} \div \underset{B}{\underline{\qquad}} \times \underset{(C - D)}{\underline{\qquad}} \times \underset{E}{\underline{\qquad}} = \underline{\qquad}$ Btu/yr

______________________ Btus
(Est. Energy Saved)

POTENTIAL ENERGY SAVING CALCULATIONS W-4

O&M

REQUIRED INFORMATION:

ENERGY MEASURES: (RETROFIT)

REQUIRED INFORMATION: Installing Solar Water Heater:

A. Percent possible sunshine (from Table 10) ______ %

B. Solar insolation incident on collector surface (from Table 18) ______ Btu/ft^2/yr

C. Collector surface area (from manufacturer) ______ sq. ft.

D. Per capita hot water consumption (from Table 17) _____gal/person/day

E. Average number of building occupants (estimated) _____occupants

F. Number of days per year building is occupied (estimated from data in Energy Inventory, Part B.1) ______ days/yr

G. Difference between hot water temperature and city water temperature (from Energy Inventory, Part E, Section d.4) ______ °F

PROCEDURES:

1. Determine annual hot water consumption:

$\underset{D}{\underline{\hspace{1.5cm}}} \times \underset{E}{\underline{\hspace{1.5cm}}} \times \underset{F}{\underline{\hspace{1.5cm}}} = \underset{(H)}{\underline{\hspace{1.5cm}}}$ gal/yr

2. Determine energy required to heat (H):

$8.3 \times \underset{(H)}{\underline{\hspace{1.5cm}}} \times \underset{G}{\underline{\hspace{1.5cm}}} = \underline{\hspace{1.5cm}}$ Btu/yr

3. Calculate usable energy from collector:

$\underset{A}{\underline{\hspace{1.5cm}}} \div 100 \times \underset{B}{\underline{\hspace{1.5cm}}} \times \underset{C}{\underline{\hspace{1.5cm}}} = \underline{\hspace{1.5cm}}$ Btu/yr

(Note: If Step 3 result is greater than Step 2 result, record Step 2 result below. If Step 3 result is less than Step 2 result, record Step 3 result below.)

____________________________Btus
(Est. Energy Saved)

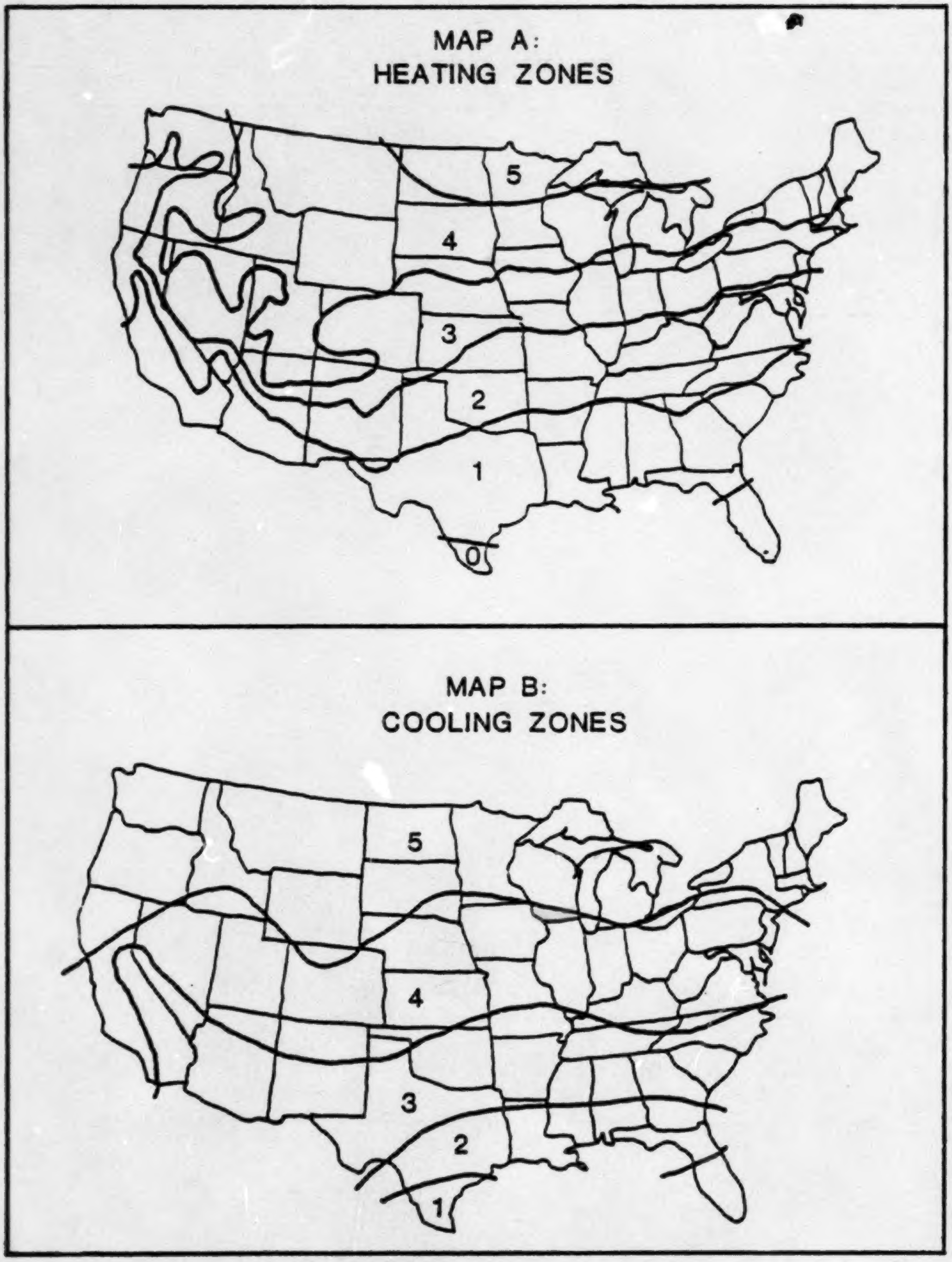
CALCULATION
REFERENCE MATERIAL

GENERAL REFERENCE. ENERGY AND POWER CONVERSIONS.*

TO CHANGE:

From:	To:	Multiply By:
Kilowatt-hours (kWh)	Btus	3,413+/11,600#
MCFs Natural Gas	Cubic feet	1000.00
	Therms	10.00
CCF Natural Gas	Btus	103,000
CF Natural Gas	Btus	1,030
Therms Natural Gas	Btus	100,000
Horsepower	kWs	0.746
	Btu/min	42.41
Barrels (bbls)	Gallons	42
Barrels Crude Oil	Btus	5,825,000
Gallons No. 2 Heating Oil	Btus	138,690
Barrels No. 5 Residual Fuel	Btus	6,287,000
Barrels No. 6 Heating Oil	Btus	6,286,980
Gallons Gasoline	Btus	125,000
Barrels Liquified Propane Gas (LPG)	Btus	4,009,950
Short Tons Coal	Btus	24,500,000
Watts (W)	Btu/hr	3.413
Kilowatts (kW)	Watts	1000.00
Pounds Steam (lbs)	Btus	1000.00+/1390.00#
Tons Refrigeration	Btu/hr	12,000

* Sea level
+ Institutional Conversion Factor
# Point of Generation Conversion Factor (for Federal Reporting)



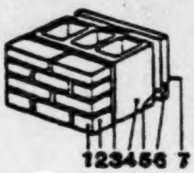
MAP A:
HEATING ZONES

MAP B:
COOLING ZONES

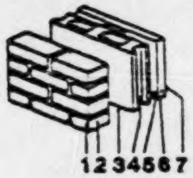
5
4
3
2
1
0
5
4
3
2
1

Figure 1. Heating and Cooling Zones.

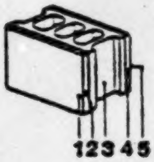
TABLE 1. U VALUES FOR TYPICAL WALL AND ROOF CONSTRUCTION (WALLS).



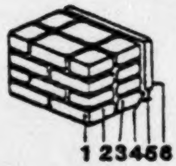
Construction	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Face brick (4 in)	0.44
3. Cement mortar (1/2 in)	0.10
4. Concrete block (cinder agg) (8 in)	1.72
5. Air space (reflective)	2.80
6. Gypsum wallboard, foil back (1/2 in)	0.45
7. Inside surface (still air)	0.68
Total resistance	6.36
U = 1/R = 1/6.36 =	0.16



Construction	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Common brick (4 in)	0.80
3. Air space	0.97
4. Concrete block (stone agg) (4 in)	0.71
5. Air space	0.97
6. Gypsum wallboard (1/2 in)	0.45
7. Inside surface (still air)	0.68
Total resistance	4.75
U = 1/R = 1/4.75 =	0.21

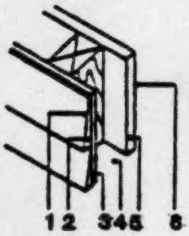


Construction	Resistance (R)
1. Inside surface (still air)	0.68
2. Plas. (lt wt agg) 5/8 in	0.39
3. Cement block (cinder agg) (4 in)	1.11
4. Plas. (lt wt agg) 5/8 in	0.39
5. Inside surface (still air)	0.68
Total resistance	3.25
U = 1/R = 1/3.25 =	0.31

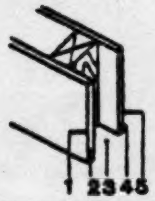


Construction	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Face brick (4 in)	0.44
3. Common brick (4 in)	0.80
4. Air space	0.97
5. Gypsum wallboard (1/2 in)	0.45
6. Inside surface (still air)	0.68
Total resistance	3.51
U = 1/R = 1/3.51 =	0.29

Adjustment for furring (1 x 2 in @ 16 in o.c.)
= U_1 x 1.00 = 0.29 x 1.00 = 0.29



Construction	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Siding, wood, 1/2 x 8 in lapped (avg)	0.81
3. Sheathing, 1/2 asphalt impregnated	1.32
4. Air space	0.97
5. Gypsum wallboard (1/2 in)	0.45
6. Inside surface (still air)	0.68
Total resistance	4.40
U = 1/R = 1/4.12 =	0.23

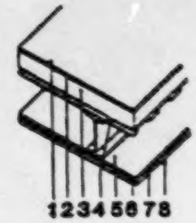


Construction	Resistance (R)
1. Surface (still air)	0.68
2. Gypsum bd (1/2 in)	0.45
3. Air space	0.97
4. Gypsum wallboard (1/2 in)	0.45
5. Surface (still air)	0.68
Total resistance	3.23
U = 1/R = 1/3.23	0.31

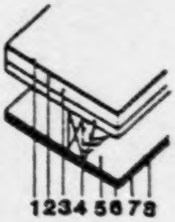
TABLE 2. U VALUES FOR GLASS.

Glass	U Value
Single pane	1.13
Double pane	0.65
Triple pane	0.47
Storm window and air space	0.56

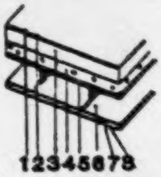
TABLE 3. U VALUES FOR TYPICAL WALL AND ROOF CONSTRUCTION (ROOFS).



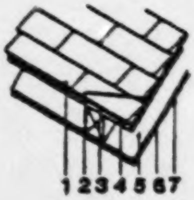
Construction	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Built-up roofing (3/8)	0.33
3. Roof insulation (C = 0.24)	4.17
4. Metal deck	0.06
5. Air space	0.99
6. Metal lath and	
7. 3/4 in plas. (san agg)	0.13
8. Inside surface (still air)	0.92
Total resistance	6.71
U = 1/R = 1/6.71	0.15



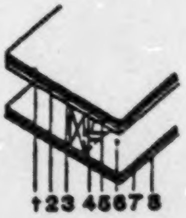
Construction (Heat flow up)	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Built-up roofing (3/8 in)	0.33
3. Roof insulation (C = 0.72)	1.39
4. Plywood deck (5/8 in)	0.78
5. Air space	0.85
6. Gypsum wallboard (1/2 in)	0.45
7. Acoustical tile (1/2 in) — glued	1.25
8. Inside surface (still air)	0.61
Total resistance	5.83
U = 1/R = 1/5,83	0.17



Construction (heat flow up)	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Built-up roofing — 3/8 in	0.33
3. Roof insulation (none)	—
4. Concrete slab (lt wt agg) (2 in)	2.22
5. Corrugated metal	0
6. Air space	0.85
7. Metal lath and 3/4 in plas. (lt wt agg)	0.47
8. Inside surface (still air)	0.61
Total resistance	4.65
U = 1/R = 1/4.65 =	0.22



Construction (Heat flow up)	Resistance (R)
1. Outside surface (15 mph wind)	0.17
2. Asphalt shingle roofing	0.44
3. Building paper	0.06
4. Plywood deck (5/8 in)	0.78
5. Air space (3.5 in, reflective surface)	2.06
6. Gypsum wallboard (1/2 in)	0.45
7. Inside surface (still air)	0.62
Total resistance	4.58
U = 1/R = 1/4.58	0.22



Heated room below unheated space

Construction (heat flow up)	Resistance (R)
1. Top surface (still air)	0.61
2. Linoleum or tile (ave R)	0.05
3. Felt	0.06
4. Plywood (5/8 in)	0.78
5. Wood subfloor (3/4 in)	0.94
6. Air space	0.85
7. Metal lath and 3/4 in plas (lt wt agg)	0.47
8. Bottom surface (still air)	0.61
Total resistance	4.37
U = 1/R = 1/4.37 =	0.23

TABLE 4. DATA ON NORMAL HEATING SEASON IN U.S. CITIES.

City	Days Per Season*	Average Temp. °F
ALABAMA		
Anniston	192	50.3
Birmingham	193	50.6
Gadsden	204	50.8
Mobile	151	54.9
Montgomery	168	53.4
Tuscaloosa	191	51.8
ARIZONA		
Flagstaff	328	42.1
Nogales	214	53.2
Phoenix	149	55.0
Prescott	243	46.3
Tucson	165	54.2
Yuma	113	56.6
ARKANSAS		
Fort Smith	187	48.0
Little Rock	187	49.1
Texarkana	171	51.2
CALIFORNIA		
Bakersfield	181	53.3
Beaumont	230	52.7
Bishop	239	47.3
Burbank	211	56.4
Fresno	192	51.8
Los Angeles	190	57.4
Mount Shasta	306	45.7
Oakland	365	56.3
Pasadena	245	56.6
Sacramento	211	52.7
San Diego	224	58.0
San Francisco	365	56.6
San Jose	244	55.1
COLORADO		
Alamosa	343	39.8
Boulder	277	45.1
Colorado Springs	276	41.4
Denver	266	43.7
Grand Junction	241	41.0
Pueblo	257	42.8
CONNECTICUT		
Bridgeport	260	42.3
Hartford	264	41.7
New Haven	268	42.5
DELAWARE		
Dover	238	45.7
Milford	232	46.5
Wilmington	235	44.1
DISTRICT OF COLUMBIA		
Washington	223	45.9
Silver Hill Obs.	232	45.4
FLORIDA		
Daytona Beach	122	57.9
Fort Myers	3	-
Jacksonville	132	56.6
Lakeland	87	57.5
Miami	100	63.3
Miami Beach	0	-
Orlando	165	61.1
Pensacola	151	55.5
Tallahassee	157	55.3
Tampa	93	57.8
GEORGIA		
Athens	191	50.3
Atlanta	194	50.5
Augusta	172	52.6
Columbus	180	51.7
Macon	169	52.9
Savannah	164	54.6
IDAHO		
Boise	277	43.7
Lewiston	269	44.6
Pocatello	290	40.9
Salmon	307	39.2
ILLINOIS		
Bloomington	242	41.5
Cairo	201	46.3
Chicago	251	39.9
Decatur	242	42.3
Joliet	257	39.4
Moline	248	39.3
Peoria	248	40.5
Rockford	268	39.5
Springfield	228	42.1
INDIANA		
Evansville	255	47.9
Fort Wayne	255	40.3
INDIANA (cont'd)		
Indianapolis	229	42.6
South Bend	257	39.6
IOWA		
Burlington	243	39.9
Davenport	240	39.6
Des Moines	243	39.2
Dubuque	268	37.9
Sioux City	253	37.3
KANSAS		
Dodge City	231	43.1
Goodland	261	40.6
Salina	232	43.6
Topeka	222	42.8
Wichita	220	44.2
KENTUCKY		
Frankfort	229	46.6
Lexington	233	43.6
Louisville	217	45.3
LOUISIANA		
Baton Rouge	157	54.8
Lake Charles	151	54.8
New Orleans	135	56.3
Shreveport	163	52.0
MAINE		
Caribou	344	35.4
Eastport	365	42.4
Portland	303	39.7
MARYLAND		
Annapolis	236	46.0
Baltimore	248	48.1
Cambridge	225	46.1
MASSACHUSETTS		
Boston	262	42.9
Fitchburg	284	41.7
Nantucket	297	44.5
Pittsfield	301	39.4
MICHIGAN		
Ann Arbor	276	40.1
Detroit	259	40.3
Flint	286	39.9
Grand Rapids	260	40.1

* For calculations requiring heating season in weeks, divide number of days by seven.

Table 4. Continued.

City	Days Per Season*	Average Temp. °F
MICHIGAN (cont'd)		
Kalamazoo	272	40.5
Lansing	268	38.9
Saginaw	275	39.3
St. Joseph	269	42.0
MINNESOTA		
Duluth	319	35.3
Minneapolis	263	35.1
Rochester	274	35.5
St. Paul	264	35.4
MISSISSIPPI		
Jackson	175	52.4
Meridian	180	52.0
Vicksburg	165	52.9
MISSOURI		
Columbia	231	42.9
Kansas City	220	42.8
St. Joseph	226	41.4
St. Louis	215	44.2
MONTANA		
Billings	286	40.2
Butte	365	38.3
Great Falls	307	40.4
Havre	298	37.4
Helena	318	39.4
Kalispell	323	40.1
Missoula	312	39.8
NEBRASKA		
Lincoln	237	40.3
Norfolk	257	37.5
North Platte	260	39.8
Omaha	239	39.2
Scottsbluff	272	39.8
NEVADA		
Ely	304	40.5
Las Vegas	206	53.2
Reno	296	44.6
Tonopah	269	43.4
NEW HAMPSHIRE		
Concord	291	38.8
Hanover	309	39.1
Keene	307	40.7
NEW JERSEY		
Atlantic City	244	45.6
Belvidere	259	42.6
Dover	276	42.3
Jersey City	246	43.9
Newark	242	43.3
New Brunswick	256	43.9
Somerville	254	43.1
Trenton	239	43.8
NEW MEXICO		
Albuquerque	222	45.2
Clayton	251	44.5
Raton	285	42.5
Roswell	208	48.5
Santa Fe	287	43.9
NEW YORK		
Albany	256	40.3
Binghamton	268	40.5
Buffalo	273	40.0
Elmira	274	41.6
Ithaca	279	40.9
New York	241	44.0
Rochester	271	39.7
Schenectady	265	38.4
Syracuse	263	40.2
NORTH CAROLINA		
Asheville	233	47.5
Charlotte	204	49.3
Hatteras	193	52.6
Raleigh	202	49.8
Winston-Salem	216	47.8
NORTH DAKOTA		
Bismarck	290	33.9
Fargo	287	32.7
Grand Forks	313	33.8
Jamestown	308	34.5
OHIO		
Cincinnati	223	44.7
Cleveland	249	42.0
Columbus	238	42.8
Dayton	243	42.0
Lima	262	42.4
Sandusky	249	41.5
OHIO (cont'd)		
Toledo	258	40.2
Youngstown	257	41.0
OKLAHOMA		
Muskogee	211	47.9
Oklahoma City	194	46.9
Tulsa	195	46.6
OREGON		
Astoria	365	51.3
Baker	314	42.4
Eugene	300	49.1
Meacham	345	42.1
Medford	270	48.2
Portland	276	50.0
Salem	292	49.3
PENNSYLVANIA		
Allentown	251	41.6
Altonna	273	42.6
Erie	258	41.3
Harrisburg	241	43.2
Lancaster	257	43.7
Philadelphia	228	45.2
Pittsburgh	234	43.4
Reading	238	43.7
Scranton	258	41.6
Williamsport	253	41.7
RHODE ISLAND		
Block Island	280	44.1
Providence	257	43.2
SOUTH CAROLINA		
Charleston	165	54.3
Columbia	181	52.4
Florence	187	51.6
Spartanburg	201	49.9
SOUTH DAKOTA		
Huron	265	29.8
Rapid City	286	26.3
Sioux Falls	268	29.3
TENNESSEE		
Chattanooga	209	48.8
Knoxville	209	47.8
Memphis	186	48.8
Nashville	204	47.8

* For calculations requiring heating season in weeks, divide number of days by seven.

Table 4. Continued.

City	Days Per Season*	Average Temp. °F
TEXAS		
Abilene	175	49.8
Amarillo	228	45.9
Austin	151	53.7
Corpus Christi	121	56.6
Dallas	162	41.0
El Paso	183	59.6
Fort Worth	166	50.8
Galveston	137	56.2
Houston	138	55.8
Lubbock	207	47.7
Palestine	160	52.6
Port Arthur	143	55.5
San Antonio	145	54.1
Waco	158	52.2
Wichita Falls	184	48.6
UTAH		
Blanding	273	42.5
Logan	290	41.7
Ogden	258	49.4
Salt Lake City	252	43.3
VERMONT		
Burlington	281	37.0
Northfield	328	38.6
VIRGINIA		
Charlottesville	238	47.3
Danville	211	48.4
Norfolk	207	49.9
Richmond	216	47.8
Roanoke	226	46.6
WASHINGTON		
Bellingham	365	50.2
Ellensburg	295	42.8
Everett	365	48.7
Olympia	365	49.9
Seattle-Tacoma	343	49.6
Spokane	301	42.2
WEST VIRGINIA		
Charleston	229	45.7
Fairmont	246	44.5
Huntington	220	46.5
WEST VIRGINIA (cont'd)		
Parkersburg	231	44.4
Wheeling	276	46.1
WISCONSIN		
Eau Claire	281	36.6
Green Bay	284	35.9
Madison	264	37.3
Milwaukee	271	39.4
Oshkosh	280	38.1
Sheboygan	291	39.6
WYOMING		
Casper	296	39.2
Cheyenne	307	40.4
Lander	298	37.1
Rock Spring	307	37.4
Sheridan	296	38.3

* For calculations requiring heating season in weeks, divide number of days by seven.

TABLE 5. AIR CONDITIONING DATA.

Building Type	ft^2/ton
Hospitals	270
Schools and Colleges	260
Public Office Buildings	340
Nursing Homes	275

TABLE 6. APPROXIMATE POWER INPUTS.

System	Total kW/Design Ton
Window Units	1.78
Through-Wall Units	1.94
Dwelling Unit, Central Air-Cooled	1.63
Central, Group, or Building Cooling Plants	
(3 to 25 tons) Air-Cooled	1.40
(25 to 100 tons) Air-Cooled	1.39
(25 to 100 tons) Water-Cooled	1.11
(Over 100 tons) Water-Cooled	0.99

TABLE 7. ESTIMATED EQUIVALENT FULL-LOAD OPERATING HOURS FOR NORMAL COOLING SEASON.

Albuquerque, NM	1500	Indianapolis, IN	1100
Atlantic City, NJ	650	Little Rock, AR	1900
Birmingham, AL	1700	Minneapolis, MN	600
Boston, MA	800	New Orleans, LA	2100
Burlington, VT	400	New York, NY	750
Charlotte, NC	900	Newark, NJ	650
Chicago, IL	750	Oklahoma City, OK	1500
Cleveland, OH	600	Pittsburgh, PA	1050
Cincinnati, OH	1250	Rapid City, SD	900
Columbia, SC	1300	St. Joseph, MO	1300
Corpus Christi, TX	2250	St. Petersburg, FL	2100
Dallas, TX	1400	San Diego, CA	1250
Denver, CO	600	Savannah, GA	1300
Des Moines, IA	800	Seattle, WA	800
Detroit, MI	850	Syracuse, NY	600
Duluth, MN	400	Trenton, NJ	900
El Paso, TX	1200	Tulsa, OK	1850
Honolulu, HI	2500	Washington, DC	950

TABLE 8. DATA ON NORMAL COOLING SEASON FOR SELECTED U.S. CITIES.*

City	Cooling Season Length in Days	Average Cooling Season Temp.
Albany, NY	133	75°F
Albuquerque, NM	189	80°F
Atlanta, GA	210	79°F
Bismarck, ND	126	78°F
Boise, ID	140	78°F
Boston, MA	133	75°F
Billings, MT	126	77°F
Buffalo, NY	133	74°F
Charleston, SC	252	79°F
Chicago, IL	147	76°F
Corpus Christi, TX	301	81°F
Dallas, TX	238	83°F
Denver, CO	161	77°F
Detroit, MI	133	75°F
Ellsworth, SD	140	77°F
Fairchild, WA	112	75°F
Greensboro, NC	196	79°F
Helena, MT	105	75°F
Kansas City, MO	182	80°F
Kodiak, AK	7	67°F
Las Vegas, NV	245	88°F
Los Angeles, CA	231	71°F
Louisville, KY	182	80°F
Lubbock, TX	217	80°F
Memphis, TN	210	81°F
Miami, FL	350	80°F
Minneapolis, MN	133	76°F
New Orleans, LA	280	80°F
Omaha, NB	161	78°F
Pearl Harbor, HI	364	80°F
Phoenix, AZ	287	87°F
Pittsburgh, PA	154	75°F
Portland, ME	105	73°F
Portland, OR	112	72°F
Roosevelt Rds, PR	364	83°F
Sacramento, CA	224	84°F
Salt Lake City, UT	140	79°F
San Diego, CA	210	70°F
San Francisco, CA	168	71°F
Traverse City, MI	119	74°F
Tulsa, OK	210	81°F
Washington, DC	168	77°F

* For calculations requiring cooling season in weeks, divide number of days by seven.

TABLE 9. TOTAL SOLAR INSOLATION ON A VERTICAL SURFACE ($Btu/yr/ft^2$).

Degrees Latitude	East- and West-Facing	North-Facing	South-Facing
24°	353,300	113,700	354,600
28°	344,800	108,200	378,400
32°	336,300	102,700	402,100
36°	325,900	97,900	423,900
40°	315,500	93,100	445,600
44°	306,250	90,000	455,800
48°	297,000	86,900	466,100
52°	284,150	83,500	458,600
56°	271,300	80,200	451,000

TABLE 10. MEAN PERCENTAGE OF POSSIBLE SUNSHINE FOR SELECTED LOCATIONS.

State and Station	Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
ALABAMA														
Birmingham	56	43	49	56	63	66	67	62	65	66	67	58	44	59
Montgomery	49	51	53	61	69	73	72	66	69	69	71	64	48	64
ALASKA														
Anchorage	19	39	46	56	58	50	51	45	39	35	32	33	29	45
Fairbanks	20	34	50	61	68	55	53	45	35	31	28	38	29	44
Juneau	14	30	32	39	37	34	35	28	30	25	18	21	18	30
Nome	29	44	46	48	53	51	48	32	26	34	35	36	30	41
ARIZONA														
Phoenix	64	76	79	83	88	93	94	84	84	89	88	84	77	85
Yuma	52	83	87	91	94	97	98	92	91	93	93	90	83	91
ARKANSAS														
Little Rock	66	44	53	57	62	67	72	71	73	71	74	58	47	62
CALIFORNIA														
Eureka	49	40	44	50	53	54	56	51	46	52	48	42	39	49
Fresno	55	46	63	72	33	89	94	97	97	93	87	73	47	78
Los Angeles	63	70	69	70	67	68	69	80	81	80	76	79	72	73
Red Bluff	39	50	60	65	75	79	86	95	94	89	77	64	50	75
Sacramento	48	44	57	67	76	82	90	96	95	92	82	65	44	77
San Diego	68	68	67	68	66	60	60	67	70	70	70	76	71	68
San Francisco	64	53	57	63	69	70	75	68	63	70	70	62	54	66
COLORADO														
Denver	64	67	67	65	63	61	69	68	68	71	71	67	65	67
Grand Junction	57	58	62	64	67	71	79	76	72	77	74	67	58	69
CONNECTICUT														
Hartford	48	46	55	56	54	57	60	62	60	57	55	46	46	56
DISTRICT OF COLUMBIA														
Washington	66	46	53	56	57	61	64	64	62	62	61	54	47	58
FLORIDA														
Apalachicola	26	59	62	62	71	77	70	64	63	62	74	66	53	65
Jacksonville	60	58	59	66	71	71	63	62	63	58	58	61	53	62
Key West	45	68	75	78	78	76	70	69	71	65	65	69	66	71
Miami Beach	48	66	72	73	73	68	62	65	67	62	62	65	65	67
Tampa	53	63	67	71	74	75	66	61	64	64	67	67	61	68
GEORGIA														
Atlanta	65	48	53	57	65	68	68	62	63	65	67	60	47	60
HAWAII														
Hilo	9	48	42	41	34	31	41	44	38	42	41	34	36	39
Honolulu	53	62	64	60	62	64	66	67	70	70	68	63	60	65
Lihue	9	48	48	48	46	51	60	58	59	67	58	51	49	54
IDAHO														
Boise	20	40	48	59	67	68	75	89	86	81	66	46	37	66
Pocatello	21	37	47	58	64	66	72	82	81	78	66	48	36	64
ILLINOIS														
Cairo	30	46	53	59	65	71	77	82	79	75	73	56	46	65
Chicago	66	44	49	53	56	63	69	73	70	65	61	47	41	59
Springfield	59	47	51	54	58	64	69	76	72	73	64	53	45	60
INDIANA														
Evansville	48	42	49	55	61	67	73	78	76	73	67	52	42	64
Ft. Wayne	48	38	44	51	55	62	69	74	69	64	58	41	38	57
Indianapolis	63	41	47	49	55	62	68	74	70	68	64	48	39	59

Table 10. Continued.

State and Station	Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
IOWA														
Des Moines	66	56	56	56	59	62	66	75	70	64	64	53	48	62
Dubuque	54	48	52	52	58	60	63	73	67	61	55	44	40	57
Sioux City	52	55	58	58	59	63	67	75	72	67	65	53	50	63
KANSAS														
Concordia	52	60	60	62	63	65	73	79	76	72	70	64	58	67
Dodge City	70	67	66	68	68	68	74	78	78	76	75	70	67	71
Wichita	46	61	63	64	64	66	73	80	77	73	69	67	59	69
KENTUCKY														
Louisville	59	41	47	52	57	64	68	72	69	68	64	51	39	59
LOUISIANA														
New Orleans	69	49	50	57	63	66	64	58	60	64	70	60	46	59
Shreveport	13	48	54	58	60	69	78	79	80	79	77	65	60	69
MAINE														
Eastport	58	45	51	52	52	51	53	55	57	54	50	37	40	50
MASSACHUSETTS														
Boston	67	47	56	57	56	59	62	64	63	61	58	48	48	57
MICHIGAN														
Alpena	45	29	43	52	56	59	64	70	64	52	44	24	22	51
Detroit	69	34	42	48	52	58	65	69	66	61	54	35	29	53
Grand Rapids	56	26	37	48	54	60	66	72	67	58	50	31	22	49
Marquette	55	31	40	47	52	53	56	63	57	47	38	24	24	47
Sault St. Marie	60	28	44	50	54	54	59	63	58	45	36	21	22	47
MINNESOTA														
Duluth	49	47	55	60	58	58	60	68	63	53	47	36	40	55
Minneapolis	45	49	54	55	57	60	64	72	69	60	54	40	40	56
MISSISSIPPI														
Vicksburg	66	46	50	57	64	69	73	69	72	74	71	60	45	64
MISSOURI														
Kansas City	69	55	57	59	60	64	70	76	73	70	67	59	52	65
St. Louis	68	48	49	56	59	64	68	72	68	67	65	54	44	61
Springfield	45	48	54	57	60	63	69	77	72	71	65	58	48	63
MONTANA														
Havre	55	49	58	61	63	63	65	78	75	64	57	48	46	62
Helena	65	46	55	58	60	59	63	77	74	63	57	48	43	60
Kalispell	50	28	40	49	57	58	60	77	73	61	50	28	20	53
NEBRASKA														
Lincoln	55	57	59	60	60	63	69	76	71	67	66	59	55	64
North Platte	53	63	63	64	62	64	72	78	74	72	70	62	58	68
NEVADA														
Ely	21	61	64	68	65	67	79	79	81	81	73	67	62	72
Las Vegas	19	74	77	78	81	85	91	84	86	92	84	83	75	82
Reno	51	59	64	69	75	77	82	90	89	86	76	68	56	76
Winnemucca	53	52	60	64	70	76	83	90	90	86	75	62	53	74
NEW HAMPSHIRE														
Concord	44	48	53	55	53	51	56	57	58	55	50	43	43	52
NEW JERSEY														
Atlantic City	62	51	57	58	59	62	65	67	66	65	54	58	52	60
NEW MEXICO														
Albuquerque	28	70	72	72	76	79	84	76	75	81	80	79	70	76
Roswell	47	69	72	75	77	76	80	76	75	74	74	74	69	74

Table 10. Continued.

State and Station	Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
NEW YORK														
Albany	63	43	51	53	53	57	62	63	61	58	54	39	38	53
Binghamton	63	31	39	41	44	50	56	54	51	47	43	29	26	44
Buffalo	49	32	41	49	51	59	67	70	67	60	51	31	28	53
Canton	43	37	47	50	48	54	61	63	61	54	45	30	31	49
New York	83	49	56	57	59	62	65	66	64	64	61	53	50	59
Syracuse	49	31	38	45	50	58	64	67	63	56	47	29	26	50
NORTH CAROLINA														
Asheville	57	48	53	56	61	64	63	59	59	62	64	59	48	58
Raleigh	61	50	56	59	64	67	65	62	62	63	64	62	52	61
NORTH DAKOTA														
Bismarck	65	52	58	56	57	58	61	73	69	62	59	49	48	59
Devils Lake	55	53	60	59	60	59	62	71	67	59	56	44	45	58
Fargo	39	47	55	56	58	62	63	73	69	60	57	39	46	59
Williston	43	51	59	60	63	66	66	78	75	65	60	48	48	63
OHIO														
Cincinnati	44	41	46	52	56	62	69	72	68	68	60	46	39	57
Cleveland	65	29	36	45	52	61	67	71	68	62	54	32	25	50
Columbus	65	36	44	49	54	63	68	71	68	66	60	44	35	55
OKLAHOMA														
Oklahoma City	62	57	60	63	64	65	74	78	78	74	68	64	57	68
OREGON														
Baker	46	41	49	56	61	63	67	83	81	74	62	46	37	60
Portland	69	27	34	41	49	52	55	70	65	55	42	28	23	48
Roseburg	29	24	32	40	51	57	59	79	77	68	42	28	18	51
PENNSYLVANIA														
Harrisburg	50	43	52	55	57	61	65	68	63	62	58	47	43	57
Philadelphia	66	45	56	57	58	61	62	64	61	62	61	53	49	57
Pittsburgh	63	32	39	45	50	57	62	64	61	62	54	39	30	51
RHODE ISLAND														
Block Island	48	45	54	47	56	58	60	62	62	60	59	50	44	56
SOUTH CAROLINA														
Charleston	61	58	60	65	72	73	70	66	66	67	68	68	57	56
Columbia	55	53	57	62	68	69	68	63	65	64	68	64	51	53
SOUTH DAKOTA														
Huron	62	55	62	60	62	65	68	76	72	66	61	52	49	63
Rapid City	53	58	62	63	62	61	66	73	73	69	66	56	54	64
TENNESSEE														
Knoxville	62	42	49	53	59	64	66	64	59	64	64	53	41	57
Memphis	55	44	51	57	64	68	74	73	74	70	69	58	45	64
Nashville	63	42	47	54	60	65	69	69	68	69	65	55	42	59
TEXAS														
Abilene	14	64	68	73	66	73	86	33	85	73	71	72	66	73
Amarillo	54	71	71	75	75	75	82	81	81	79	76	76	70	76
Austin	33	46	50	57	60	62	72	76	79	70	70	57	49	63
Brownsville	37	44	49	51	57	65	73	78	78	67	70	54	44	61
Del Rio	36	53	55	61	63	60	66	75	80	69	66	58	52	63
El Paso	53	74	77	81	85	87	87	78	78	80	82	80	73	80
Ft. Worth	33	56	57	65	66	67	75	78	78	74	70	63	58	68
Galveston	66	50	50	55	61	69	76	72	71	70	74	62	49	63
San Antonio	57	48	51	56	58	60	69	74	75	69	67	55	49	62
UTAH														
Salt Lake City	22	48	53	61	68	73	78	82	82	84	73	56	49	69

Table 10. Continued.

State and Station	Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
VERMONT														
Burlington	54	34	43	48	47	53	59	62	59	51	43	25	24	46
VIRGINIA														
Norfolk	60	50	57	60	63	67	66	66	66	63	64	60	51	62
Richmond	56	49	55	59	63	67	66	65	62	63	64	58	50	61
WASHINGTON														
North Head	44	28	37	42	48	48	48	50	46	48	41	31	27	41
Seattle	26	27	34	42	48	53	48	62	56	53	36	28	24	45
Spokane	62	26	41	53	63	64	68	82	79	68	53	28	22	58
Tatoosh Island	49	26	36	39	45	47	46	48	44	47	38	26	23	40
Walla Walla	44	24	35	51	63	67	72	86	84	72	59	33	20	60
Yakima	18	34	49	62	70	72	74	86	86	74	61	38	29	65
WEST VIRGINIA														
Elkins	55	33	37	42	47	55	55	56	53	55	51	41	33	48
Parkersburg	62	30	36	42	49	56	60	63	60	50	53	37	29	48
WISCONSIN														
Green Bay	57	44	51	55	56	58	64	70	65	58	52	40	40	55
Madison	59	44	49	52	53	58	64	70	66	60	56	41	38	56
Milwaukee	59	44	48	53	56	60	65	73	67	62	56	44	39	57
WYOMING														
Cheyenne	63	65	66	64	61	59	68	70	68	69	69	65	63	66
Lander	57	66	70	71	66	65	74	76	75	72	67	61	62	69
Sheridan	52	56	61	62	61	61	67	76	74	67	60	53	52	64
Yellowstone Park	35	39	51	55	57	56	63	73	71	65	57	45	38	56
PUERTO RICO														
San Juan	57	64	69	71	66	59	62	65	67	61	63	63	65	65

Based on period of record through December 1959, except in a few instances. These charts and tabulation derived from "Normals, Means, and Extremes" table in U.S. Weather Bureau publication Local Climatological Data.

TABLE 11. SHADING COEFFICIENTS.

Glass	
1/8" Clear Double Strength	1.00
1/4" Clear Plate	0.93 – 0.95
1/4" Heat Absorbing Plate	0.65 – 0.70
1/4" Reflective Plate	0.23 – 0.56
1/4" Laminated Reflective	0.28 – 0.42
1" Clear Insulating Plate	0.80 – 0.83
1" Heat Absorbing Insulating Plate	0.43 – 0.45
1" Reflective Insulating Plate	0.13 – 0.31

Shading Device	With 1/4" Clear Plate Glass	With 1" Clear Insulating Glass
Venetian Blinds – Light Colored, Fully Closed	0.55	0.51
Roller Shade – Light Colored, Translucent, Fully Drawn	0.39	0.37
Drapes – Semi-Open Weave, Average Fabric Transmittance and Reflectance, Fully Closed	0.55	0.48
Reflective Polyester Film	0.24	0.20
Louvered Sun Screens		
– 23 Louvers/In.	0.15 – 0.35	0.10 – 0.29
– 17 Louvers/In.	0.18 – 0.51	0.12 – 0.45

TABLE 12. MONTHLY AND ANNUAL HEATING DEGREE DAYS (BASE 65°F).

1977-1978

State and Station	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Annual Total	Normals July-June
ALABAMA														
Birmingham	0	0	0	176	292	640	967	768	452	120	42	0	3457	2844
Huntsville	0	0	4	216	367	721	1062	855	514	129	60	0	3928	3302
Mobile	0	0	0	73	149	439	731	551	268	16	0	0	2227	1684
Montgomery	0	0	0	87	164	479	756	601	326	50	2	0	2465	2269
ALASKA														
Anchorage	75	144	421	820	1486	1659	1349	1077	1100	771	491	308	9701	10911
Barrow	802	632	871	1382	2099	2256	2202	2223	2346	1904	1501	954	19172	20265
Bethel	269	199	520	1112	1619	1673	1421	1463	1577	1026	645	590	12114	13203
Fairbanks	101	124	573	1216	2184	2480	2013	1712	1576	898	454	304	13635	14345
Gulkana	217	221	575	1046	2105	2415	2152	1620	1502	1013	671	429	13966	13938
Juneau	243	196	428	695	1062	1423	1233	922	954	683	525	317	8681	9007
Kodiak	321	360	446	785	1026	1163	894	884	911	752	650	435	8628	8860
Kotzebue	204	183	622	1247	1845	1984	1612	1807	1985	1408	883	537	14317	16039
Nome	274	272	598	1169	1619	1756	1338	1487	1682	1195	705	605	12700	14323
St. Paul Island	499	420	508	862	1043	1045	968	1049	1216	896	803	615	9925	11119
Talkeetna	145	178	551	958	1714	1830	1455	1159	1214	877	531	372	10984	11708
Valdez	280	305	496	741	1210	1422	1181	1008	1021	754	575	429	9422	10545
ARIZONA														
Flagstaff	9	19	157	432	715	843	1032	954	756	677	478	128	6200	7322
Phoenix	0	0	0	0	42	155	254	172	67	25	0	0	715	1552
Tucson	0	0	0	1	117	242	365	313	144	64	24	0	1270	1752
Winslow	0	0	5	207	593	716	849	720	448	326	175	0	4039	4733
ARKANSAS														
Fort Smith	0	0	0	142	377	773	1143	924	537	113	69	0	4078	3336
Little Rock	0	0	0	105	370	709	1025	862	436	68	48	0	3623	3354
CALIFORNIA														
Bakersfield	0	0	0	12	162	237	311	241	82	124	13	0	1182	2185
Eureka	302	200	231	342	408	427	403	404	347	415	357	264	4100	4679
Fresno	0	0	0	46	302	417	415	343	143	182	19	0	1867	2650
Long Beach	0	0	0	4	35	125	265	223	88	104	12	5	861	1606
Los Angeles	1	0	0	19	62	120	195	184	116	168	46	3	914	1819
Oakland	46	14	15	86	257	334	334	303	185	213	92	57	1936	2909
Sacramento	0	0	17	68	309	472	451	362	235	269	46	0	2229	2843
San Diego	0	0	0	0	37	55	117	117	52	43	8	0	429	1507
San Francisco	103	48	55	139	284	385	381	335	238	295	161	135	2559	3042
Stockton	0	0	2	41	284	451	449	358	191	212	16	0	2004	2806
COLORADO														
Alamosa	19	51	246	621	951	1252	1302	1103	900	647	516	126	7734	8609
Colorado Springs	2	22	73	413	784	938	1231	1036	741	479	386	98	6203	6473
Denver	2	14	38	358	737	920	1206	936	665	435	335	87	5733	6016
Grand Junction	0	1	17	214	736	975	1098	852	561	373	210	9	5046	5605
Pueblo	0	4	34	343	723	894	1228	1001	653	347	238	54	5519	5394

Table 12. Continued.

1977-1978

State and Station	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Annual Total	Normals July-June
CONNECTICUT														
Bridgeport	4	3	52	248	442	970	1181	1136	904	536	265	43	5784	5461
Hartford	1	8	112	399	610	1141	1276	1192	920	500	220	25	6404	6350
DELAWARE														
Wilmington	0	1	31	353	550	975	1165	1179	842	433	191	17	5737	4940
DISTRICT OF COLUMBIA														
Washington Dulles	1	2	23	339	521	985	1163	1066	748	317	123	14	5302	5010
Washington National	0	0	1	196	406	829	1001	933	633	219	86	0	4304	4211
FLORIDA														
Fort Myers	0	0	0	5	34	133	212	216	69	0	0	0	669	457
Jacksonville	0	0	0	70	135	366	508	484	221	22	1	0	1807	1327
Key West	0	0	0	0	0	36	92	85	10	0	0	0	223	64
Miami	0	0	0	0	6	58	123	99	34	0	0	0	320	206
Orlando	0	0	0	6	38	179	275	255	71	0	0	0	824	73
Tallahassee	0	0	0	93	175	433	620	548	271	42	0	0	2182	1563
Tampa	0	0	0	18	53	222	320	323	99	4	0	0	1039	718
GEORGIA														
Athens	0	0	2	187	298	663	913	721	410	99	38	0	3331	2975
Atlanta	0	0	4	178	313	701	966	714	412	137	57	0	3482	3095
Augusta	0	0	0	153	215	578	797	689	380	93	33	0	2938	2547
Columbus	0	0	0	110	186	530	781	634	334	63	11	0	2649	2378
Savannah	0	0	0	96	165	457	645	594	283	35	2	0	2277	1952
HAWAII														
Hilo	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Honolulu	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kahului	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IDAHO														
Boise	8	32	145	362	758	853	859	744	500	488	329	74	5152	5833
Lewiston	16	17	153	435	761	868	911	673	531	441	272	40	5118	5464
Pocatello	1	38	189	447	831	990	1045	875	678	567	431	119	6211	7063
ILLINOIS														
Chicago	0	8	42	413	741	1254	1521	1346	1020	518	264	46	7173	6497
Moline	0	5	50	420	780	1337	1625	1417	986	423	229	13	7285	6395
Peoria	0	6	39	418	734	1301	1595	1383	1006	405	222	14	7123	6098
Rockford	0	20	88	488	849	1393	1658	1471	1101	519	259	29	7875	6845
Springfield	0	2	21	340	661	1172	1521	1348	968	334	186	4	6557	5558
INDIANA														
Evansville	0	0	3	289	495	970	1377	1228	774	233	137	0	5506	4624
Fort Wayne	2	11	62	429	694	1218	1509	1482	1051	485	224	26	7193	6209
Indianapolis	0	0	30	326	575	1104	1443	1313	873	292	150	4	6110	5577
South Bend	2	18	58	443	669	1206	1436	1401	1041	480	233	41	7028	6462

Table 12. Continued.

1977-1978

State and Station	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Annual Total	Normals July-June
IOWA														
Des Moines	0	3	35	388	769	1289	1667	1442	988	627	181	9	7198	6710
Dubuque	1	43	121	500	924	1472	1770	1491	1122	521	268	41	8274	7277
Sioux City	0	9	55	428	878	1309	1778	1534	1007	487	194	33	7712	6953
Waterloo	2	56	144	584	923	1490	1932	1610	1133	539	224	23	8660	7415
KANSAS														
Concordia	0	0	23	291	703	1085	1512	1299	803	326	162	9	6213	5623
Goodland	2	10	40	377	776	1033	1431	1263	782	456	315	50	6535	6119
Topeka	0	0	6	263	662	1075	1473	1240	824	280	156	6	5985	5243
Wichita	0	0	1	176	558	926	1375	1149	663	194	112	6	5160	4687
KENTUCKY														
Covington	0	2	32	391	586	1118	1440	1303	880	346	207	10	6315	5070
Lexington	0	0	6	277	498	972	1338	1219	755	254	179	6	5504	4729
Louisville	0	0	6	295	472	935	1294	1145	720	221	142	1	5231	4640
LOUISIANA														
Baton Rouge	0	0	0	56	144	387	694	546	258	29	2	0	2116	1670
Lake Charles	0	0	0	36	136	367	682	539	236	22	2	0	2020	1498
New Orleans	0	0	0	43	113	342	646	556	191	2	0	0	1893	1465
Shreveport	0	0	0	72	260	549	933	746	374	61	30	0	3025	2167
MAINE														
Caribou	56	93	408	657	944	1489	1702	1467	1364	894	333	156	9563	9632
Portland	29	54	233	518	761	1219	1353	1276	1071	724	377	136	7749	7498
MARYLAND														
Baltimore	0	0	9	278	476	904	1101	1048	715	318	141	9	4999	4729
MASSACHUSETTS														
Blue Hill	7	17	148	419	640	1109	1278	1188	997	618	284	50	6755	6335
Boston	0	4	85	304	498	948	1127	1057	885	480	209	18	5615	5621
Worcester	16	32	189	481	711	1202	1359	1255	1054	674	288	69	7330	6848
MICHIGAN														
Detroit Metro	1	17	85	524	729	1218	1400	1357	1077	580	235	65	7288	6419
Flint	7	35	97	496	701	1210	1444	1438	1178	632	238	87	7563	7041
Grand Rapids	3	48	99	501	759	1204	1407	1413	1140	584	213	62	7433	6801
Lansing	7	50	118	514	757	1226	1461	1496	1215	627	244	84	7799	6904
Sault St. Marie	111	246	335	621	910	1396	1675	1503	1377	889	333	270	9666	9193
MINNESOTA														
Duluth	46	196	347	636	1101	1662	1852	1520	1212	794	324	176	9866	9756
International Falls	34	246	367	666	1266	1908	2126	1745	1436	832	312	195	11133	10547
Minneapolis	0	35	145	548	1016	1565	1842	1488	1080	584	162	46	8511	8159
St. Cloud	6	90	191	582	1103	1674	1911	1561	1169	683	238	92	9300	8868
MISSISSIPPI														
Jackson	0	0	0	136	246	538	881	706	377	73	14	0	2971	2300
Meridian	0	0	0	108	200	517	808	714	457	111	26	0	2941	2388

Table 12. Continued.

1977-1978

State and Station	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Annual Total	Normals July-June
MISSOURI														
Columbia Regional	0	0	14	287	591	1053	1378	1206	842	260	161	3	5795	5078
Kansas City	0	0	21	293	673	1094	1487	1266	848	291	172	6	6151	5357
St. Louis	0	0	11	291	601	1059	1401	1223	840	275	158	5	5864	4750
Springfield	0	0	4	233	522	906	1396	1172	763	258	134	7	5395	4570
MONTANA														
Billings	0	59	208	463	988	1380	1668	1366	933	545	357	97	8064	7265
Glasgow	32	140	292	583	1208	1752	2081	1610	1252	628	319	111	1008	8969
Great Falls	37	119	280	527	1021	1502	1776	1410	966	622	421	106	8787	7652
Havre	20	95	230	531	1124	1640	1936	1473	1108	546	286	79	9074	8687
Helena	52	92	270	593	1008	1367	1485	1175	806	512	361	87	7808	8190
Missoula	59	76	310	637	1001	1245	1259	1050	771	564	511	171	7654	7931
NEBRASKA														
Lincoln	0	0	42	413	793	1230	1703	1447	972	410	193	27	7230	6218
Norfolk	0	5	45	423	882	1318	1756	1477	965	471	187	28	7557	6981
North Platte	2	34	96	458	869	1236	1662	1400	924	491	275	71	7518	6743
Omaha	0	3	28	361	754	1196	1637	1375	910	372	160	17	6813	6049
Scottsbluff	0	23	72	407	800	1131	1444	1199	752	458	286	54	6626	6774
NEVADA														
Ely	9	43	238	535	850	1056	1101	959	742	716	521	172	6942	7814
Las Vegas	0	0	0	3	226	399	522	356	168	91	16	0	1781	2601
Reno	10	12	154	392	687	821	858	739	544	582	387	113	5299	6022
NEW HAMPSHIRE														
Concord	37	58	222	551	760	1360	1466	1435	1138	725	270	72	8094	7360
Mt. Washington	538	551	768	1091	1233	1796	1924	1855	1805	1393	861	634	14449	13878
NEW JERSEY														
Atlantic City	2	0	28	311	457	910	1069	1146	826	463	256	24	5492	4946
Newark	0	0	50	319	527	975	1168	1099	814	411	190	13	5566	5034
Trenton	0	0	38	321	519	944	1134	1080	800	418	189	15	5458	4947
NEW MEXICO														
Albuquerque	0	0	1	192	551	757	870	713	454	215	175	2	3930	4292
Clayton	0	3	17	268	637	806	1148	968	627	314	236	36	5060	5207
Roswell	0	0	0	68	349	551	895	593	294	45	39	3	2837	3697
NEW YORK														
Albany	7	51	156	471	666	1179	1340	1306	1051	642	245	84	7198	6888
Buffalo	5	40	110	473	646	1146	1376	1378	1130	670	282	81	7337	6927
Rochester	0	44	113	477	634	1127	1298	1360	1087	634	220	63	7066	6719
Syracuse	14	60	121	444	624	1162	1348	1322	1097	677	252	92	7213	6678

Page 184/EA-WB

Table 12. Continued.

1977-1978

State and Station	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Annual Total	Normals July-June
NORTH CAROLINA														
Asheville	0	0	14	331	466	868	1101	878	586	241	139	0	4624	4237
Charlotte	0	0	3	215	356	690	862	785	473	140	72	0	3596	3218
Greensboro	0	0	7	307	459	821	1039	927	605	245	131	4	4545	3825
Raleigh	0	0	4	283	411	768	914	883	514	196	83	0	4056	3514
NORTH DAKOTA														
Bismarck	17	111	246	574	1153	1687	2066	1564	1143	663	257	105	9586	9044
Fargo	7	95	211	549	1178	1817	2061	1721	1284	668	209	90	9890	9271
Williston	8	131	267	577	1212	1759	2091	1600	1148	655	252	91	9791	9161
OHIO														
Akron	4	21	68	458	632	1130	1413	1366	1013	533	247	51	6936	6224
Cleveland	4	26	60	378	592	1103	1387	1343	1005	534	218	43	6693	6154
Columbus	1	17	36	394	594	1091	1420	1346	938	424	223	23	6507	5702
Dayton	0	7	45	403	605	1108	1428	1339	927	395	205	15	6477	5641
Toledo	3	29	71	481	713	1241	1490	1484	1121	573	243	43	7492	6381
OKLAHOMA														
Oklahoma City	0	0	0	115	420	766	1192	990	493	90	64	0	4130	3695
Tulsa	0	0	1	118	412	801	1236	989	541	110	67	0	4275	3680
OREGON														
Eugene	68	20	178	385	637	675	690	576	508	503	375	102	4717	4739
Medford	14	4	105	360	673	694	646	571	444	451	262	44	4268	4930
Pendleton	20	35	200	461	792	927	1011	714	593	504	322	46	5625	5240
Portland	40	19	131	339	644	707	764	561	485	430	317	58	4495	4792
Salem	57	23	181	392	606	670	727	547	513	476	316	51	4559	4852
PENNSYLVANIA														
Erie	9	51	110	477	636	1131	1395	[illegible]	1143	688	303	84	7435	6851
Harrisburg	0	5	35	377	562	1029	1196	[illegible]	810	414	173	17	5793	5224
Philadelphia	0	0	24	328	558	998	1139	1121	797	423	161	10	5559	4865
Pittsburgh	11	41	78	442	583	1043	1307	1229	860	412	209	38	6253	5930
Scranton	14	37	119	505	653	1090	1252	1279	984	562	240	73	6808	6277
RHODE ISLAND														
Block Island	0	3	84	301	508	899	1104	1073	946	624	358	72	5972	5771
Providence	0	6	103	368	568	1030	1231	1192	964	542	238	26	6268	5972
SOUTH CAROLINA														
Charleston	0	0	0	112	175	459	663	616	309	52	18	0	2404	2146
Columbia	0	0	1	192	277	629	850	741	418	109	37	0	3254	2598

Table 12. Continued.

1977-1978

State and Station	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Annual Total	Normals July-June
SOUTH DAKOTA														
Huron	0	27	129	506	1002	1530	2007	1620	1099	624	247	89	8880	8055
Rapid City	1	48	163	494	944	1330	1669	1383	912	588	312	91	7935	7324
Sioux Falls	0	22	125	530	1000	1503	1957	1576	1063	613	252	78	8719	7838
TENNESSEE														
Bristol	0	0	19	359	455	913	1207	1005	620	286	130	4	4998	4306
Knoxville	0	0	3	242	374	764	1097	846	487	148	74	0	4035	3478
Memphis	0	0	0	123	313	640	995	835	454	74	47	0	3481	3227
Nashville	0	0	3	255	425	813	1152	996	556	164	92	0	4456	3696
Oak Ridge	0	0	10	352	448	890	1161	946	577	232	110	2	4728	3944
TEXAS														
Amarillo	0	0	1	150	522	768	1107	972	551	136	139	6	4352	4183
Austin	0	0	0	16	136	354	750	561	225	15	7	0	2064	1737
Brownsville	0	0	0	0	25	101	342	286	66	6	0	0	826	650
Corpus Christi	0	0	0	4	56	160	502	382	101	17	0	0	1222	930
Dallas/Ft. Worth	0	0	0	55	257	536	962	786	346	54	41	0	3037	2382
El Paso	0	0	0	56	328	472	603	449	200	57	22	0	2187	2678
Galveston	0	0	0	6	63	238	606	501	204	16	2	0	1636	1224
Lubbock	0	0	0	80	373	611	1014	864	419	75	64	0	3500	3545
Midland	0	0	0	47	295	478	823	586	245	49	30	0	2553	2621
San Antonio	0	0	0	19	138	360	667	521	192	27	4	0	1928	1570
UTAH														
Milford	0	16	110	399	782	898	973	794	611	533	377	42	5535	6412
Salt Lake City	0	11	73	282	670	835	880	697	522	433	293	36	4732	5983
VERMONT														
Burlington	24	53	207	564	740	1314	1539	1547	1202	781	225	90	8286	7876
VIRGINIA														
Norfolk	0	0	0	158	321	661	860	902	580	235	72	3	3792	3488
Richmond	0	0	4	259	401	784	974	964	627	235	88	5	4341	3939
Roanoke	0	0	18	350	496	896	1147	989	637	261	112	4	4910	4307
Wallops Island	0	0	7	259	436	818	968	963	687	308	196	9	4651	4240
WASHINGTON														
Olympia	166	90	242	502	734	829	711	596	587	502	367	91	5417	5530
Seattle	78	41	185	387	609	704	657	522	487	423	307	70	4470	4727
Spokane	57	56	289	563	921	1197	1154	862	701	576	412	101	6889	6835
Yakima	32	24	217	491	862	968	992	753	588	464	311	73	5775	6009

Table 12. Continued.

1977-1978

State and Station	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Annual Total	Normals July-June
WEST VIRGINIA														
Beckley	8	11	67	479	564	997	1319	1211	801	366	216	56	6095	5615
Charleston	0	2	19	357	482	919	1249	1138	691	258	137	23	5275	4590
Huntington	0	0	35	332	455	919	1232	1122	698	254	164	12	5223	4624
Parkersburg	0	0	12	351	518	989	1292	1185	788	338	168	21	5662	4817
WISCONSIN														
Green Bay	3	64	162	544	942	1454	1658	1500	1227	733	279	107	8673	8098
La Crosse	1	40	122	488	936	1483	1804	1515	1106	565	209	36	8305	7417
Madison	6	95	161	533	925	1404	1688	1466	1096	608	269	59	8310	7730
Milwaukee	8	47	106	485	827	1302	1531	1356	1086	667	335	83	7833	7444
WYOMING														
Casper	3	51	164	492	945	1240	1481	1191	854	605	471	107	7604	7555
Cheyenne	21	74	150	511	910	1108	1324	1115	840	627	491	157	7328	7255
Lander	2	50	183		986	1193	1466	1192	823	586	490	127		7869
Sheridan	12	73	233	528	1001	1452	1654	1323	951	543	463	153	8386	7708

TABLE 13. MONTHLY AND ANNUAL COOLING DEGREE DAYS (BASE 65°F).

1976

State and Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Total	Normals Jan.-Dec.
ALABAMA														
Birmingham	0	8	25	27	48	290	418	376	219	15	1	0	1427	1928
Huntsville	0	3	14	8	43	257	380	360	142	8	0	0	1215	1808
Mobile	0	17	74	160	245	454	578	504	321	48	4	0	2405	2577
Montgomery	0	3	23	34	75	367	482	436	287	23	0	0	1730	2238
ALASKA														
Anchorage	0	0	0	0	0	0	3	0	0	0	0	0	3	0
Barrow	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bethel	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fairbanks	0	0	0	0	0	2	23	14	0	0	0	0	39	52
Gulkana	0	0	0	0	0	0	8	0	0	0	0	0	8	9
Juneau	0	0	0	0	0	0	3	3	0	0	0	0	6	0
Kodiak	0	0	0	0	0	0	5	0	0	0	0	0	5	0
Kotzebue	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nome	0	0	0	0	0	0	0	1	0	0	0	0	1	0
St. Paul Island	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Summit	0	0	0	0	0	0	0	0	0	0			0	0
Tackeetna	0	0	0	0	0	1	0	4	0	0	0	0	5	6
Valdez	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARIZONA														
Flagstaff	0	0	0	0	0	15	70	13	0	0	0	0	98	140
Phoenix	6	4	34	169	495	692	833	804	548	289	91	0	3965	3508
Tucson	2	0	14	89	306	557	597	636	386	139	34	0	2760	2814
Winslow	0	0	0	0	45	209	413	298	84	0	0	0	1049	1203
ARKANSAS														
Fort Smith	0	4	9	33	54	239	435	388	187	16	0	0	1365	2022
Little Rock	0	5	27	37	65	292	480	434	220	42	0	0	1602	1925
CALIFORNIA														
Bakersfield	0	6	15	34	326	447	643	445	406	204	32	0	2558	2179
Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fresno	0	0	2	16	162	254	456	246	228	73	0	0	1437	1671
Long Beach	34	0	17	8	56	215	271	295	286	232	85	0	1499	985
Los Angeles	29	2	7	1	1	111	163	141	167	143	96	3	864	615
Oakland	0	0	0	0	21	75	6	29	35	32	0	0	198	128
Sacramento	0	0	1	8	167	278	363	270	213	83	8	0	1391	1159
San Diego	14	0	10	3	31	147	196	240	269	200	102	0	1212	722
San Francisco	0	0	0	0	21	88	4	23	33	23	0	0	192	108
Stockton	0	0	0	0	81	248	392	288	273	121	0	0	1403	1259
COLORADO														
Alamosa	0	0	0	0	0	1	25	0	0	0	0	0	26	88
Colorado Springs	0	0	0	0	0	66	227	114	28	0	0	0	435	461
Denver	0	0	0	0	3	112	324	176	52	0	0	0	667	625
Grand Junction	0	0	0	0	32	195	460	324	103	0	0	0	1114	1140
Pueblo	0	0	0	0	9	163	365	239	76	0	0	0	852	981

Table 13. Continued.

1976

State and Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Total	Normals Jan.-Dec.
CONNECTICUT														
Bridgeport	0	0	0	10	6	205	204	266	78	6	0	0	775	735
Hartford	0	0	0	47	18	257	236	208	47	6	0	0	819	584
DELAWARE														
Wilmington	0	0	0	37	25	260	291	276	106	6	0	0	1003	992
DISTRICT OF COLUMBIA														
Washington Dulles	0	0	0	28	24	208	232	215	65	7	0	0	779	940
Washington National	0	4	1	92	86	383	424	370	179	15	0	0	1554	1415
FLORIDA														
Fort Myers	42	86	213	193	386	423	521	531	436	246	122	66	3265	3711
Jacksonville	0	16	85	60	213	350	528	462	360	85	13	7	2179	2596
Key West	133	175	382	343	487	476	611	598	565	453	289	198	4710	4888
Miami	92	144	336	309	424	429	569	530	470	361	209	141	4014	4038
Orlando	18	75	194	196	374	449	549	529	474	247	65	49	3219	3226
Tallahassee	0	4	51	94	241	395	537	526	367	57	14	6	2292	2563
Tampa	17	63	199	175	348	424	525	517	440	202	63	45	3018	3366
GEORGIA														
Athens	0	2	11	50	89	282	410	376	177	18	0	0	1415	1722
Atlanta	0	1	8	30	67	273	359	346	159	11	0	0	1254	1589
Augusta	0	0	30	51	127	320	482	419	228	34	0	0	1691	1995
Columbus	0	5	25	63	119	351	493	460	282	36	0	0	1834	2143
Savannah	0	12	68	53	164	331	526	416	306	70	7	1	1954	2317
HAWAII														
Hilo	201	186	214	222	255	268	302	355	364	357	291	261	3276	3066
Honolulu	278	209	275	311	393	402	464	498	479	446	315	325	4395	4221
Kahului	196	196	248	283	315	329	423	456	424	411	300	309	3890	3732
IDAHO														
Boise	0	0	0	0	19	66	263	130	55	2	0	0	535	714
Lewiston	0	0	0	0	15	62	288	178	139	5	0	0	687	657
Pocatello	0	0	0	0	1	46	227	70	28	0	0	0	372	437
ILLINOIS														
Chicago	0	0	0	36	6	178	286	196	56	8	0	0	766	664
Moline	0	0	0	26	12	175	341	221	72	13	0	0	860	893
Peoria	0	0	0	28	14	176	326	180	62	14	0	0	800	968
Rockford	0	0	0	21	3	137	270	159	31	5	0	0	626	714
Springfield	0	0	3	28	34	228	393	214	98	23	0	0	1021	1116
INDIANA														
Evansville	0	0	6	47	40	258	379	274	98	10	0	0	1112	1364
Fort Wayne	0	0	0	26	9	193	254	140	38	4	0	0	664	748
Indianapolis	0	0	0	21	15	198	284	205	43	4	0	0	770	974
South Bend	0	0	1	37	13	192	249	150	36	4	0	0	682	695

Table 13. Continued.

1976

State and Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Total	Normals Jan.-Dec.
IOWA														
Des Moines	0	0	0	19	36	203	385	283	104	20	0	0	1050	928
Dubuque	0	0	0	9	3	112	266	144	29	8	0	0	571	606
Sioux City	0	0	0	13	26	181	359	294	89	7	0	0	969	932
Waterloo	0	0	0	10	10	131	282	175	55	5	0	0	668	675
KANSAS														
Concordia	0	0	0	10	29	246	458	443	182	32	0	0	1400	1302
Goodland	0	0	0	0	22	149	357	275	64	1	0	0	868	925
Topeka	0	0	1	34	40	242	410	376	171	20	0	0	1294	1361
Wichita	0	0	2	19	32	270	420	464	187	23	0	0	1417	1673
KENTUCKY														
Covington	0	0	6	59	28	207	276	202	39	5	0	0	822	1000
Lexington	0	0	9	30	26	193	257	205	46	4	0	0	770	1197
Louisville	0	0	21	47	51	243	372	294	92	10	0	0	1130	1268
LOUISIANA														
Baton Rouge	2	25	82	123	195	394	506	501	367	51	2	0	2248	2585
Lake Charles	0	23	70	127	234	400	490	503	383	47	4	0	2281	2739
New Orleans	4	18	100	132	234	404	509	518	390	68	13	0	2390	2706
Shreveport	2	26	58	116	112	326	428	432	288	48	7	0	1843	2538
MAINE														
Caribou	0	0	0	0	6	104	52	65	4	0	0	0	231	128
Portland	0	0	0	0	2	128	80	93	5	0	0	0	308	252
MARYLAND														
Baltimore	0	1	0	58	51	315	317	284	114	9	0	0	1149	1108
MASSACHUSETTS														
Blue Hill	0	0	0	48	13	184	171	150	30	3	0	0	599	457
Boston	0	0	0	43	25	276	251	231	61	8	0	0	895	661
Worcester	0	0	0	37	7	154	110	119	16	0	0	0	443	387
MICHIGAN														
Detroit Metro	0	0	0	30	10	182	246	182	53	3	0	0	706	654
Flint	0	0	0	20	5	155	196	140	41	3	0	0	560	438
Grand Rapids	0	0	0	27	4	158	239	161	49	0	0	0	638	575
Lansing	0	0	0	25	4	162	198	121	45	1	0	0	556	535
Sault St. Marie	0	0	0	3	2	29	33	88	12	0	0	0	167	139
MINNESOTA														
Duluth	0	0	0	0	0	53	75	117	26	0	0	0	271	176
International Falls	0	0	0	0	0	80	76	98	27	0	0	0	281	176
Minneapolis	0	0	0	14	14	223	351	269	72	7	0	0	950	585
St. Cloud	0	0	0	5	0	122	193	197	40	0	0	0	557	426
MISSISSIPPI														
Jackson	0	17	52	76	116	357	497	481	300	47	0	0	1943	2321
Meridian	0	8	33	36	57	268	409	389	220	18	0	0	1438	2231

Table 13. Continued.

1976

State and Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Total	Normals Jan.-Dec.
MISSOURI														
Columbia Regional	0	0	0	22	21	160	409	326	130	22	0	0	1090	1269
Kansas City	0	0	0	22	29	199	444	399	169	34	0	0	1296	1420
St. Louis	0	0	8	38	34	239	458	298	129	25	0	0	1229	1475
Springfield	0	0	7	20	28	173	367	305	156	29	0	0	1085	1382
MONTANA														
Billings	0	0	0	0	1	21	276	200	49	0	0	0	547	498
Glasgow	0	0	0	0	9	41	180	172	35	0	0	0	437	438
Great Falls	0	0	0	0	6	51	174	116	37	5	0	0	389	339
Havre	0	0	0	0	2	36	220	193	42	3	0	0	496	395
Helena	0	0	0	0	0	14	102	45	10	0	0	0	171	256
Missoula	0	0	0	0	0	21	89	41	7	0	0	0	158	188
NEBRASKA														
Lincoln	0	0	0	15	26	216	413	354	144	10	0	0	1178	1148
Norfolk	0	0	0	11	32	200	387	324	100	6	0	0	1060	925
North Platte	0	0	0	0	5	62	247	192	27	0	0	0	533	802
Omaha	0	0	0	21	34	240	440	358	139	17	0	0	1249	1173
Scottsbluff	0	0	0	0	18	146	359	240	66	1	0	0	830	666
NEVADA														
Ely	0	0	0	0	0	18	103	2	4	0	0	0	127	
Las Vegas	0	0	2	57	404	500	687	641	419	93	6	0	2809	2946
Reno	0	0	0	0	0	25	144	34	33	0	0	0	236	329
NEW HAMPSHIRE														
Concord	0	0	0	18	9	184	100	99	8	1	0	0	419	349
Mt. Washington	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NEW JERSEY														
Atlantic City	0	0	0	13	15	201	238	221	74	3	0	0	765	864
Newark	0	0	0	50	30	281	317	305	110	6	0	0	1099	1024
Trenton	0	0	0	52	34	283	292	281	105	6	0	0	1053	968
NEW MEXICO														
Albuquerque	0	0	0	0	38	260	382	319	137	5	0	0	1141	1316
Clayton	0	0	0	0	7	152	244	240	81	3	0	0	727	767
Roswell	0	0	7	57	159	436	429	478	211	9	0	0	1786	1560
NEW YORK														
Albany	0	0	0	19	11	184	120	120	22	0	0	0	476	574
Buffalo	0	0	0	8	7	149	109	119	40	0	0	0	432	437
Rochester	0	0	0	24	9	189	150	138	55	1	0	0	566	531
Syracuse	0	0	0	16	2	141	84	83	31	0	0	0	357	551

Table 13. Continued.

1976

State and Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Total	Normals Dec.-Jan.
NORTH CAROLINA														
Asheville	0	0	0	0	5	135	198	170	35	2	0	0	545	872
Charlotte	0	2	11	43	76	238	374	351	146	14	0	0	1255	1596
Greensboro	0	4	14	71	55	212	344	257	82	9	0	0	1048	1341
Raleigh	0	3	31	71	116	304	428	330	157	19	0	0	1459	1394
OHIO														
Akron	0	0	0	16	14	139	132	101	22	0	0	0	424	634
Cleveland	0	0	3	23	14	167	214	138	39	2	0	0	600	613
Columbus	0	0	3	23	23	174	223	135	25	2	0	0	608	809
Dayton	0	0	2	30	27	175	259	147	28	1	0	0	669	936
Toledo	0	0	0	31	10	155	230	137	34	2	0	0	599	685
OKLAHOMA														
Oklahoma City	0	1	23	33	62	300	468	512	253	50	0	0	1702	1876
Tulsa	0	6	7	28	52	307	520	461	256	48	0	0	1685	1949
OREGON														
Eugene	0	0	0	0	3	12	101	82	30	3	0	0	231	239
Medford	0	0	0	0	6	34	215	110	66	5	0	0	436	562
Pendleton	0	0	0	0	20	53	270	129	103	3	0	0	578	656
Portland	0	0	0	0	4	23	89	66	30	4	0	0	216	300
Salem	0	0	0	0	0	6	59	48	16	3	0	0	132	232
PENNSYLVANIA														
Erie	0	0	0	10	5	98	81	110	33	2	0	0	339	373
Harrisburg	0	0	0	47	22	283	233	240	73	3	0	0	901	1025
Philadelphia	0	0	0	64	58	326	326	315	115	7	0	0	1211	1104
Scranton	0	0	0	46	16	198	145	159	37	0	0	0	601	608
RHODE ISLAND														
Block Island	0	0	0	18	10	166	128	138	21		0	0		359
Providence	0	0	0	40	13	196	163	183	33	3	0	0	631	532
SOUTH CAROLINA														
Charleston	2	9	73	70	187	329	502	384	274	52	2	1	1885	2076
Columbia	2	10	58	87	160	295	460	442	231	30	0	0	1775	2087
SOUTH DAKOTA														
Huron	0	0	0	0	2	170	313	328	75	3	0	0	891	711
Rapid City	0	0	0	0	4	83	251	248	87	3	0	0	676	661
Sioux Falls	0	0	0	2	24	226	370	324	85	9	0	0	1040	719

Table 13. Continued.

1976

State and Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Total	Normals Jan.-Dec.
TENNESSEE														
Bristol	0	0	2	14	24	185	262	212	54	0	0	0	753	1107
Knoxville	0	3	1	26	48	273	356	314	107	5	0	0	1133	1569
Memphis	0	7	44	64	84	349	519	438	247	48	0	0	1800	2029
Nashville	0	1	28	36	68	257	363	299	92	10	0	0	1154	1694
Oak Ridge	0	1	0	6	17	187	273	234	53	0	0	0	771	1367
TEXAS														
Amarillo	0	0	0	13	32	223	312	318	110	5	0	0	1013	1433
Austin	0	57	85	115	186	451	479	577	401	61	6	0	2418	2908
Brownsville	41	97	216	283	343	507	511	547	509	190	59	24	3327	3874
Corpus Christi	25	84	170	265	299	505	510	563	498	136	31	3	3089	3474
Dallas/Ft. Worth	0	32	59	52	138	421	537	602	338	72	0	0	2251	2587
El Paso	0	0	4	71	170	441	418	434	179	18	0	0	1735	2098
Galveston	0	6	40	156	259	457	516	550	445	113	7	0	2549	3004
Lubbock	0	1	0	45	93	369	317	406	187	4	0	0	1422	1647
Midland	0	10	21	68	155	398	344	434	219	22	0	0	1671	2250
San Antonio	3	62	113	136	202	451	467	521	383	45	0	0	2383	2994
UTAH														
Milford	0	0	0	0	0	55	306	121	30	0	0	0	512	688
Salt Lake City	0	0	0	0	34	151	431	237	87	3	0	0	943	927
VERMONT														
Burlington	0	0	0	24	19	185	135	97	23	0	0	0	483	396
VIRGINIA														
Norfolk	1	13	11	102	110	337	417	347	193	27	0	0	1558	1441
Richmond	0	8	9	99	91	307	389	337	133	12	0	0	1385	1353
Roanoke	0	0	8	53	49	179	285	230	58	1	0	0	863	1030
Wallops Island	0	0	0	16	17	194	288	274	146	19	0	0	954	1107
WASHINGTON														
Olympia	0	0	0	0	0	2	9	3	0	0	0	0	14	101
Seattle	0	0	0	4	1	6	41	14	7	0	0	0	73	183
Spokane	0	0	0	0	0	24	143	93	33	0	0	0	293	388
Yakima	0	0	0	0	0	27	156	103	50	0	0	0	336	479
WEST VIRGINIA														
Beckley	0	0	2	38	7	90	127	86	6	0	0	0	356	490
Charleston	0	1	17	58	54	218	238	175	39	1	0	0	801	1055
Huntington	0	1	24	51	59	224	244	228	32	4	0	0	867	1098
Parkersburg	0	0	16	49	39	180	229	184	41	3	0	0	741	1045
WISCONSIN														
Green Bay	0	0	0	8	1	129	219	122	41	0	0	0	520	386
La Crosse	0	0	0	5	7	167	304	228	60	10	0	0	781	695
Madison	0	0	0	14	6	136	270	165	34	2	0	0	627	460
Milwaukee	0	0	0	24	5	144	247	181	62	4	0	0	667	450
WYOMING														
Casper	0	0	0	0	0	29	250	127	33	0	0	0	439	458
Cheyenne	0	0	0	0	0	7	145	50	15	0	0	0	217	327
Lander	0	0	0	0	1	41	238	84	30	0	0	0	394	383
Sheridan	0	0	0	0	0	28	211	115	28	0	0	0	382	446

TABLE 14. HEAT LOSS FOR VARIOUS PIPE SIZES, INSULATION THICKNESSES, AND WATER TEMPERATURES.

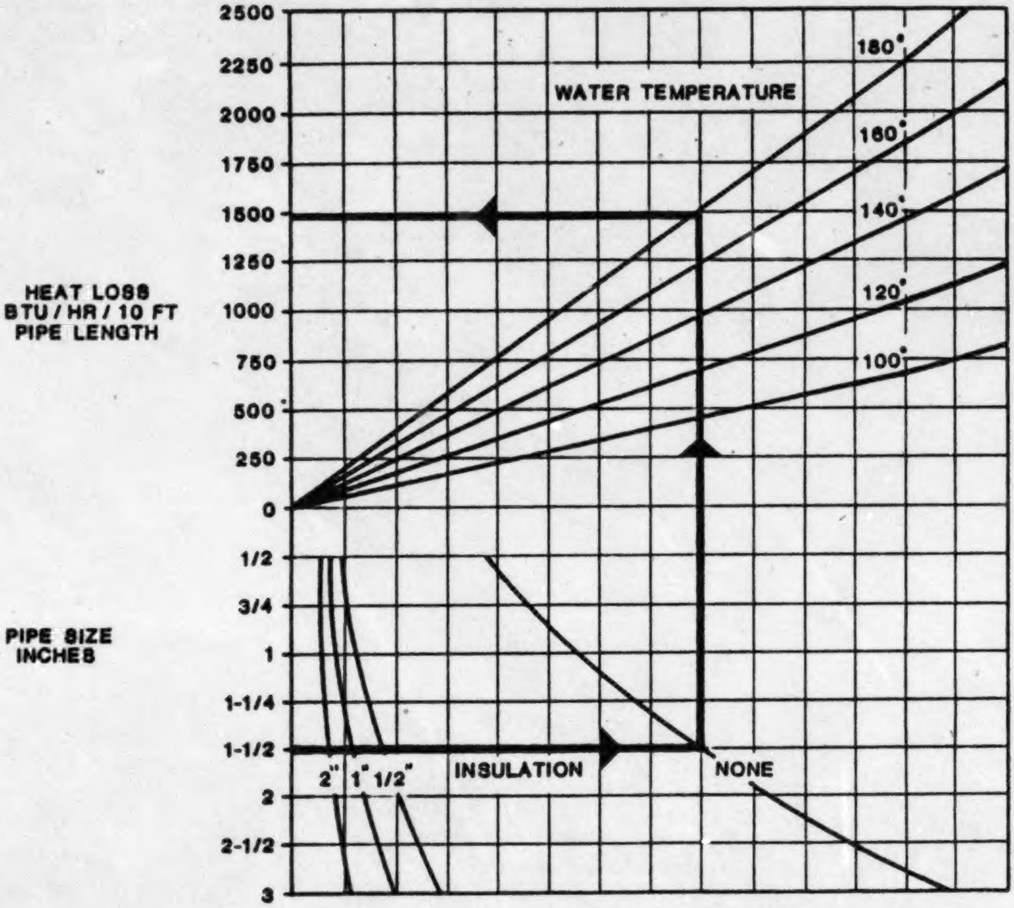


TABLE 15. HEAT LOSS FOR VARIOUS PIPE SIZES, INSULATION THICKNESSES, AND WATER TEMPERATURES.

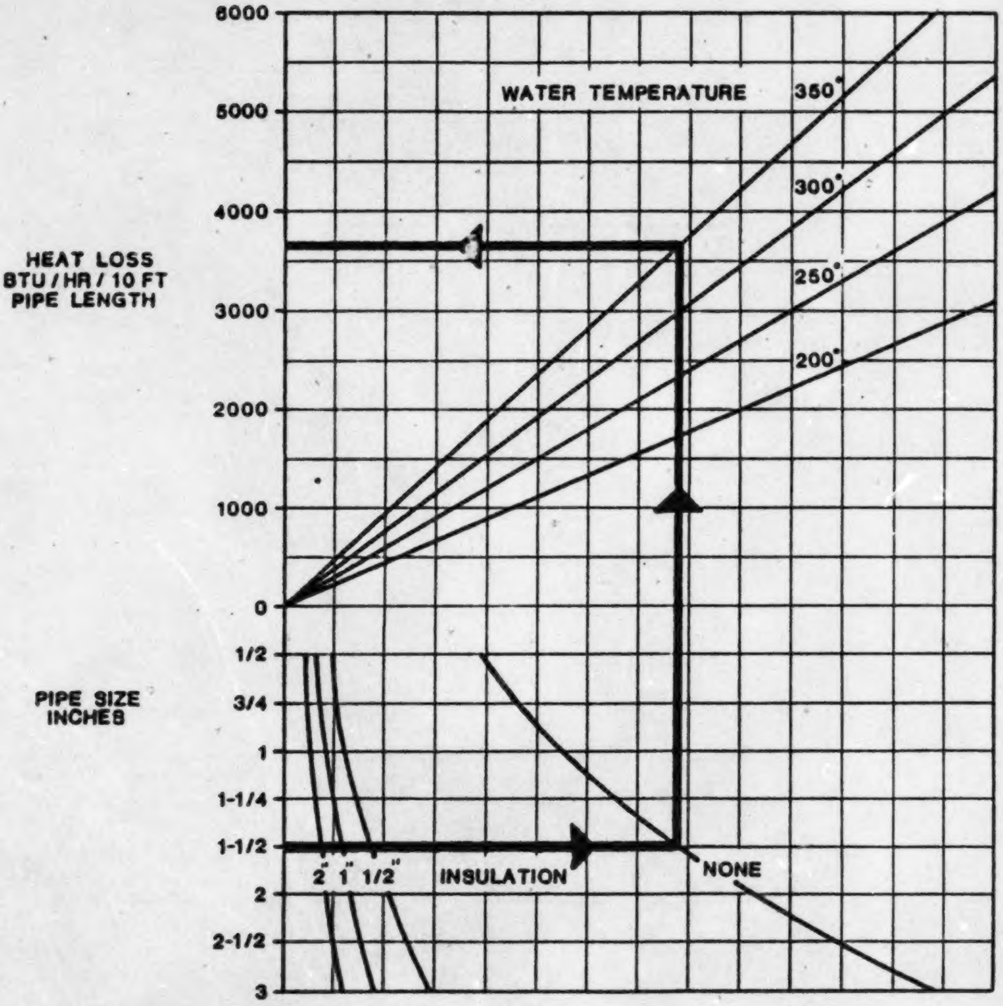


TABLE 16. HEAT GAIN FOR VARIOUS PIPE SIZES AND INSULATION THICKNESSES (45° WATER).

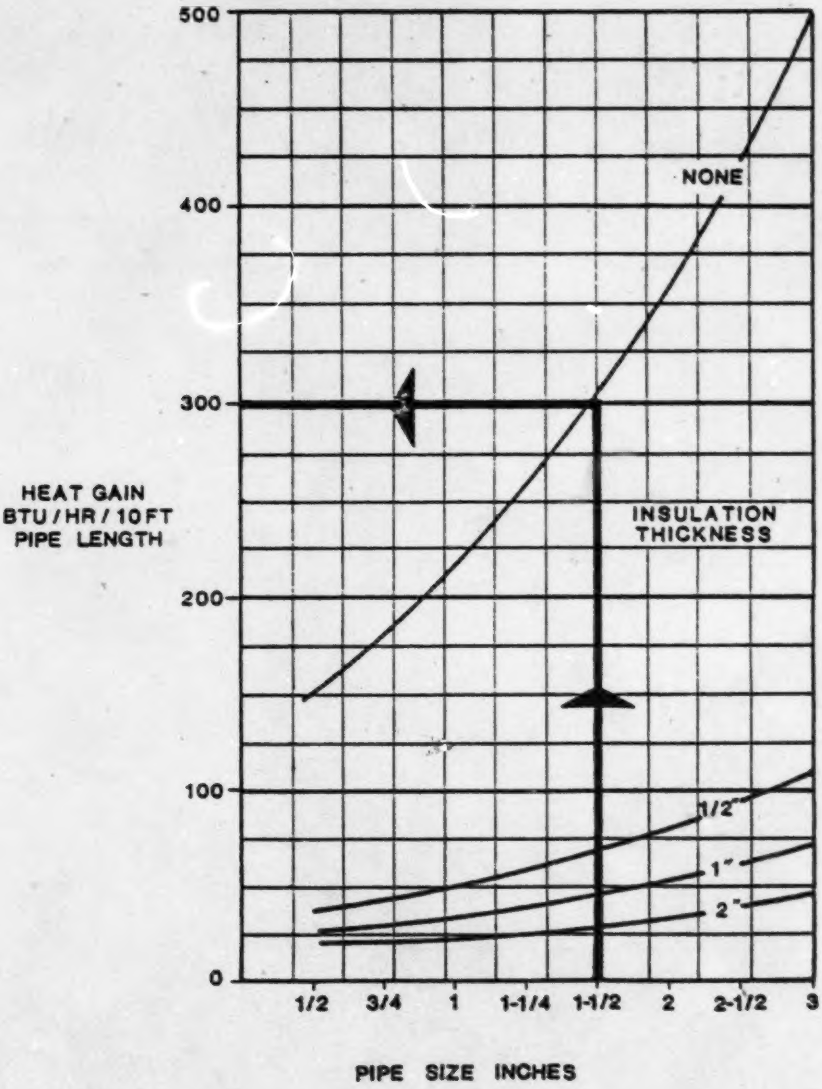


TABLE 17. AVERAGE HOT WATER CONSUMPTION FOR VARIOUS INSTITUTIONS.

Institution	Average Daily Consumption
Dormitories	13 gallons/student
Hospitals	18 gallons/bed
Elementary Schools	1 gallon/student
Jr. & Sr. High Schools	2 gallons/student
Office Buildings	1 gallon/person

TABLE 18. SOLAR INSOLATION FOR COLLECTORS TILTED 10° PLUS NORTH LATITUDE FROM HORIZONTAL.

Degrees North Latitude	Solar Insolation ($Btu/yr/ft^2$)
24°	815,100
28°	800,800
32°	786,500
36°	766,800
40°	747,000
44°	717,900
48°	688,700
52°	647,100
56°	605,600